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Vol. 222 — **NOVEMBER, 1936** — **No. 5**

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Entered at the Post Office at Lancaster, Pa., March 14, 1928, as second-class matter under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on July 3, 1919.

Published by

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA
Prince and Lemon Streets, Lancaster, Penna., and
Twentieth Street and Parkway, Philadelphia, Penna.

SIX DOLLARS PER YEAR (Foreign Postage Additional) **SINGLE NUMBERS, SIXTY CENTS**

Indexes to the semi-annual volumes of the JOURNAL are published with the June and December numbers. The contents are also indexed in *The Industrial Arts Index.*

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Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 222 NOVEMBER, 1936 No. 5

ADVANCES AND DEVELOPMENTS IN WEATHER FORECASTING.*

BY

R. HANSON WEIGHTMAN,
U. S. Weather Bureau.

INTRODUCTION.

From the very dawn of history the study of the weather has profited mankind. It impressed on his mind the importance of dividing the year into seasons, of selecting times for the sowing and harvesting of his crops, of determining favorable times to undertake voyages in ships, and of constructing shelter to protect him from the severity of the elements. We, in the present era, owe the many facilities and comforts we accept as a matter of course to the ability of those who have gone before us to profit by their collective experience.

Should we follow the progress made in our knowledge of predicting the weather, we would find that it falls quite easily into four stages or phases: (1) the preservation of remembered or written records of past weather events; (2) the establishment of sequence relations between the appearance of the sky or other phenomena and the weather, as evidenced by weather lore; (3) the development of practical forecasting based on simultaneous weather conditions over extensive

* Presented at a meeting held Thursday, January 30, 1936.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

areas largely on an empirical basis; and (4) growth of our knowledge of the physical causes of weather phenomena and improved technique in weather forecasting. The first resulted in the development of certain agricultural customs and domestic practices as to clothing, housing and habitat. In St. Matthew's Gospel, Chapter XVI, 2d and 3d verses, will be found an example of a sequence relation. When the Pharisees and the Sadducees asked Christ for a sign from heaven, "He answered and said unto them: When it is evening, ye say it will be fair weather; for the sky is red. And in the morning, it will be foul weather today for the sky is red and lowring." Some weather sayings may be traced back some thousand or more years before the Christian era and similar ones are found in substantially the same form among widely scattered races. From a translation of a cuneiform tablet now in the British Museum we learn that predictions authorized with the forecaster's name were addressed to the King. One of these dealing with thunder, moon and crops may bear quotation as follows: "When it thunders in the day of the moon's disappearance, the crops will prosper and the market will be steady." Speculations about weather occupied the minds of the Greek philosophers and the formal treatise on meteorology written by Aristotle in the 4th century B.C. remained the standard for more than 2,000 years.

Weather records accumulated from numerous points throughout the world were at first made without instruments but during the early part of the 19th century a number began to be partly instrumental and were more complete and regular. The earliest regular weather record in the United States, of which we have knowledge, was made by the Rev. John Campanus in 1644 and 1645 at the Swedes Fort, near Wilmington, Del., and the next earliest was kept at Boston by the Hon. Paul Dudley in 1729–1730. However, the credit for taking the first official weather observations belongs to the Army Medical Department. An order dated May 2, 1814, made it the duty of hospital surgeons to keep a diary of the weather. Shortly thereafter in 1818, every surgeon was provided with a good thermometer. In 1817 a system of thrice daily observations was instituted in the Land Office.

It is of interest to note that as early as 1838 a grant of money, the first of its kind, was made by the Legislature of Pennsylvania to the Franklin Institute for the collection of weather information.

From the interchange and plotting of observations more and more became known about the weather and American meteorologists, including Maury, Loomis, Espy, Redfield, Henry, Coffin, and Ferrel had a very important part in these early developments. A contribution was also made by one whom Philadelphians and, in fact, the whole nation loves to remember, namely, Benjamin Franklin. In September, 1743, being interested in noting an eclipse of the moon, he was very much chagrined by the sky becoming overcast at Philadelphia and preventing the observation of the eclipse. He learned later that at Boston the eclipse was seen and over before the storm began. From these facts he correctly deduced that weather travels, and this important principle is one that forecasters employ in making their weather predictions to the present day.

SURFACE CYCLONES AND ANTICYCLONES.

When surface observations of wind direction were charted it was found that there were in evidence well-organized wind systems which came to be known as cyclones and anticyclones. In the cyclonic system winds blow spirally inward toward a center turning counterclockwise in the northern hemisphere. In the anticyclone the air flows spirally outward from a center turning clockwise in the northern hemisphere. The direction of the spirals in the cyclone and anticyclone is reversed in the southern hemisphere.

When the readings of the barometric pressure (or weight of the air), reduced to some common plane for which sea level has been almost universally adopted, were plotted on a chart and lines of equal pressure drawn it was found that the pressure contours took the form of valleys and hills, very much like those found on topographic charts. Furthermore, the hills corresponded in location to the anticyclonic wind systems and the valleys to the cyclonic.

It was found also that the cyclones and anticyclones of the temperate zone moved in general in the same direction

as the prevailing westerly winds. In the torrid zone the prevailing winds blow from east to west and disturbances that occurred there moved similarly from east to west. Careful studies resulted in a great deal being learned about the distribution of the winds of the globe, especially the trade winds.

The red letter year perhaps in the history of applied meteorology was 1845. On the 1st of April in that year, a commercial telegraph line was opened to public use. After that date many saw the possibility of forecasting the weather by the obvious process of telegraphing ahead what weather was coming. However, the first person to actually begin work of this kind was Joseph Henry, Secretary of the Smithsonian Institution. By the end of 1849, 150 people at widely scattered points were taking observations and reporting them to the Smithsonian Institution. The next step was the construction of a daily map which the Institution undertook in 1850. But it was not until about 1870 that deductions began to be made regularly from the map and storm warnings were issued. Probably the greatest impetus to increasing knowledge of the development and behavior of weather disturbances came with the practical development of the telegraph. It may well be said that the introduction of telegraphy began a new era in meteorology, for, in reality, it made possible the daily synoptic weather chart. Telegraphy permitted the daily collection of observations taken at the same time over large areas and a daily program of collecting reports became the practice of the more important nations. From such practice and studies based on it, empirical rules developed for forecasting the coming weather. Gradually, with a contribution here and there, more and more knowledge was gained to explain the causes of our weather phenomena, mostly, however, based exclusively on surface observations of the weather elements with, of course, the assistance of the cloud observations. The configuration of isobars has a variety of patterns, the details of which are well recognized by students of the weather maps, but for a region even of the size of the eastern half of the United States, it can be stated that no two maps are the same. This seems rather remarkable when it is realized that daily maps for such comparisons are available since 1870.

VERTICAL STRUCTURE OF CYCLONES AND ANTICYCLONES.

As previously stated the only information available for studying the structure of highs and lows consisted of the surface observations and in addition the cloud types and directions. Beginning in the nineties kites were employed to secure observations of temperature above the earth's surface, but most of these attained altitudes of not over two miles and were not a part of the telegraphic observations. Pilot balloons employed here and there for some years came into fairly general use about 1917 to give more information about the direction and speed of the wind at elevations above the surface. These balloons, which are about 30 inches in diameter, are filled with hydrogen gas until they have a free lift sufficient to give them an ascensional rate of 180 meters a minute. From observations of the angular altitude and azimuth made with a theodolite at minute intervals, the speed and direction at the different levels can be obtained. These became a regular program during the World War and now about 80 such observations are received twice daily from the United States alone. Kites went out of use for a while but, beginning about 1907 they were revived by the establishment of one station and were gradually increased to six in 1918. The kite carried aloft a meteorograph, weighing about one and a half pounds, which makes a continuous record of temperature, humidity and pressure. Kites gave place to airplanes in 1931, since which time they have been in operation as a daily program. In 1935 they were increased in number to about 20, about an equal number being maintained by the Army, the Navy and the Weather Bureau. To supplement the kite and airplane and to attain much greater altitudes, occasional ascents have been made with sounding balloons. These balloons are about 6 feet in diameter when inflated and carry a meteorograph to altitudes sometimes as great as 35 km. (21 miles). During recent years efforts have been made to develop an apparatus that by the emission of radio impulses will give a record at the ground of temperature, pressure and humidity conditions above the surface to altitudes comparable to those attained by kites and airplanes. The devising of several practical types has been the result, but the cost has been rather large—

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larger in fact than the cost of an airplane observation. More recently, however, the apparatus has been simplified and the cost reduced and it is expected that shortly a satisfactory instrument will be provided for $20 or slightly less. Such instruments can function in all sorts of weather and not be subject to such deterrents as bad ground conditions, low ceiling, etc.

By means of the sounding balloons a most interesting phenomenon was discovered in 1899, namely, the isothermal layer or tropo-pause, which separates the troposphere or first 10 km. (6 miles) roughly of the atmosphere, depending on latitude and season, from the stratosphere or isothermal region, as it was formerly called, in which the temperature remains nearly constant or rises very slowly to the highest elevations reached.

It may not be out of place to emphasize how comparatively thin is the film of air in which our weather and storms take place. All of these occur below the tropopause and, with the exception of a few very well developed thunderstorms, most of them below 6 km. ($3\frac{1}{2}$ miles). The troposphere is the layer of the atmosphere next to the earth, varying in thickness from 8 km. at the poles to 16 km. at the equator. Above the tropopause is the stratosphere, whose characteristics of temperature are fairly homogeneous up to 35 km. (21 miles).

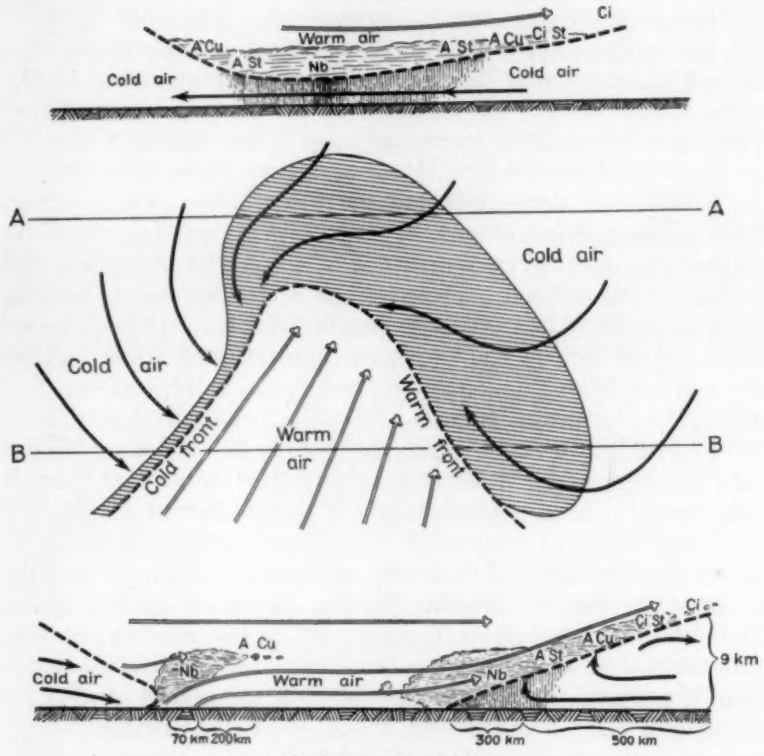
Before the World War forecasting was based largely on barometric patterns and a knowledge of how they behaved in different parts of the country. The accuracy of the predictions at that time seems quite remarkable now that we can look back a few years when many of the observational tools that we have at present were entirely lacking. Space will not permit a discussion of the rules developed from the barometric patterns in detail. It is desirable, however, to correct the impression that still prevails, in some quarters at least, that forecasts were based entirely on similarity of positions of the highs and lows. In former years through the experience gained from the weather maps, it became known that certain types of pressure distribution caused precipitation but the cause of this was not thoroughly understood.

Bjerknes Cyclone Model.—A development that greatly clarified our comprehension of such causes was the cyclone

model given to us by the Bjerknes based on their work at the Geophysical Institute at Bergen, Norway, following the World War.

According to the Bjerknes system (see Fig. 1), a cyclone consists of two essentially different air masses. The central

FIG. 1.



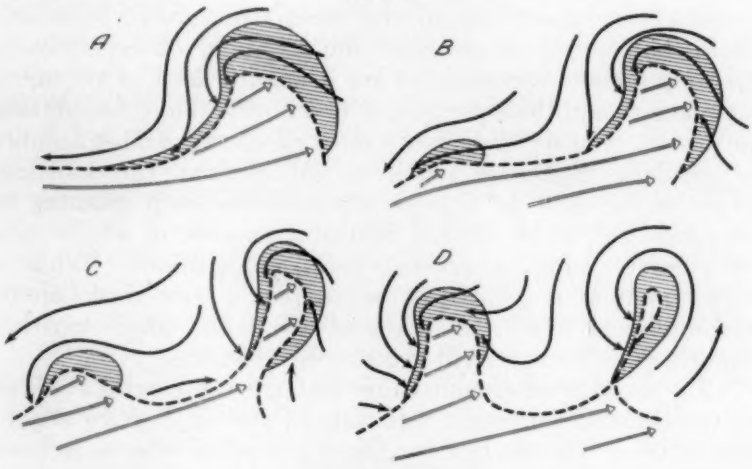
Bjerknes cyclone model.

section of the figure shows the surface distribution with a warm, moist current of south or southwest winds indicated by the double arrows constituting the warm sector and with cold air at the rear and in front of the warm sector. The warm and cold air masses are separated by fairly distinct boundary surfaces shown by the broken lines which pass through the cyclone center and are called the "cold front"

where the cold air is replacing warm air, and the "warm front" where warm air is replacing cold air. Surfaces of discontinuity are inclined in the vertical always toward the cold side at an angle of slope with the surface of the earth of the order of 1 to 75 or 100 in the case of the cold front and of about 1 to 125 or 175 in the case of the warm front. The slopes of the warm fronts and the cold fronts in the top and bottom sections are much exaggerated. The cold front in the bottom section along the line *BB* of the central section has a blunt nose near the surface due to the slowing up of the surface flow of air on account of friction and turbulence. The top of the nose is on the average at an elevation of 1,000 to 2,000 m., dependent on the temperature difference between the warm and cold sectors and the speed of the cold air mass. The upper portion of the figure shows a vertical east-west section through the cyclone north of the center along line *AA* in the central section. Here the air at the surface is moving from an easterly or northerly quarter and is quite cold, as we most always find in the northern quadrants of a low. Aloft the wind is from the southwest and being a tropical origin is relatively warm and humid. It came originally from lower levels and low latitudes, having undergone a forced ascent over the cold wedge of surface air with the result that there is considerable cloudiness and precipitation due to cooling by expansion incident to ascent. The lower portion of the figure shows another vertical east-west section through the cyclone south of the center and along the line *BB* in the central figure. At the left are seen the cold polar surface winds from the west and northwest underrunning the warm, moist tropical winds from the south and southwest which latter persist aloft after the winds have changed to westerly at the surface. This underrunning results in forced ascent of warm, moist air from the south with resulting cloudiness and occasionally heavy and, as a rule, brief showers. This front is called the "cold front" and is generally identified with the squall line or trough of the low. At the right of the section we have the relatively warm southwest winds aloft overrunning the colder surface air from the east, giving widespread cloudiness and precipitation. Between the warm front and the cold front, at and near which cloudiness and precipitation are in evidence, there

is a region of warm air and relatively clear sky and sunshine, although cumulus clouds are to be expected and at times scattered local showers because of conditions favorable to convection. It will be noted that a narrow band of showers is pictured along and immediately behind the cold front. At and immediately ahead of the warm front, on the other hand, the area over which rain is falling is relatively broad, the rain being due to the upflow of the warm, moist south and southwest current over the cold, dense current from the east and southeast, which upflow causes decreased pressure and adiabatic cooling.

FIG. 2.



Cyclone families.

Cyclones have a regular life history, they develop, increase in intensity for a while, and later die out. In the United States about 40 per cent. of the cyclones observed develop within its borders or over the waters immediately adjacent thereto. They frequently occur in families (see Fig. 2) on lines and surfaces of discontinuities separating cold, polar air from warm tropical air. The point where the development takes place is where a bend or wave develops in the line or surface of discontinuity, see Fig. 2 (*B–D*), generally to the south or southwest of the anticyclone that follows the parent low. The family or series may consist of two, three or even

four individual lows, each one starting successively farther and farther to the south and east. When the cold front advances more rapidly than the warm front, as is the case in most instances, they gradually get closer and closer together and finally meet, as indicated in Fig. 2-*D*. The south and southwest currents constituting the warm sector give place to the polar air at the surface at first, which gradually extends to greater and greater heights until the supply of warm tropical air has been shut off completely. Such a process is called as "occulsion."

Air Mass Analysis.—An examination of the pilot balloon observations in connection with the surface weather maps gives a very good idea of the wind structure of lows and highs, but actual temperature and humidity observations in the free air are necessary to get a definite idea of the more significant conditions pertaining to stability and precipitation processes. To accomplish this most effectively a large number of airplane flights is required. At present the schedule provides for only 20 airplane observations each morning to represent the whole United States, a number of which may be missing owing to adverse weather conditions. While a larger number is greatly to be desired, a good deal can be accomplished with the material available when weather conditions do not prevent the scheduled flights.

The next development came through the careful analysis of the characteristics and structure of the air, particularly in the vertical. In the last few years numerous references have appeared in the press concerning "Air Mass Analysis," many of which have been misleading, to say the least. The impression has been gained that air mass analysis was a new system of forecasting and that it would replace the methods employed for many years in this country and in most of the countries of Europe. Air mass analysis in its intensified form also originated in Norway, was taken up in this country and has been taught at two of the leading educational institutions by able instructors. Its most ardent friends, however, will not claim that it is a system of forecasting. It is properly speaking a preliminary and an aid to forecasting. There is nothing inconsistent in the analysis of air masses and the methods of forecasting employed by the U. S. Weather Bureau.

As a matter of fact, the Weather Bureau is vitally interested in developments of this kind and after satisfying itself that there is merit in them quickly adopts them into its program. For about a year the Bureau has had in its employ three graduates from the Massachusetts Institute of Technology who are devoting their entire time to improving methods of analysis and adapting them as an aid in forecasting. Air mass studies have been in progress for some years and everything developed in that line has been carefully and eagerly followed by our workers. In fact, forecasters of the Bureau have been using air mass analysis increasingly in a generalized way ever since kite and pilot balloon observations have been available and the frontal model developed. Such generalized analyses are of course less satisfactory and complete than the intensified analysis that is now being undertaken with the aid of more numerous airplane observations.

A few remarks concerning air mass analysis are necessary at this point to a proper understanding of its usefulness.

Masses of air that remain for some time over particular regions of considerable extent develop properties that are characteristic of the region, especially as regards temperature and moisture. Consider for example the Gulf of Mexico, where temperatures are high and the moisture content large. A mass of air overlying such a region gradually acquires properties that are characterized by high temperatures and large moisture content, not only at and near the surface but gradually an intermediate and finally in upper levels due mainly to convection. On the other hand let us consider the region of Northwestern Canada where in the winter season temperatures and humidities both are low. Such characteristics will be transmitted first to the lower layers by mixing due to turbulence and gradually to higher and higher levels until an equilibrium condition is finally reached. With respect to the two masses, the tropical Gulf air on the one hand and the continental Canadian air on the other, the characteristics are imparted more rapidly and to greater elevations in the former than in the latter because convection extends to high levels over the Gulf on account of the more intense surface heating in the lower latitudes. The process of transmitting these characteristics to considerable elevations

is slow, probably occupying several days over the warm Gulf and a week or more over the interior or northern Canada.

The principal classes of air from a thermal standpoint are polar, or cold, and tropical, or warm. These are further subdivided on the general basis of moisture, being separated into two main classes depending on whether the source is land and dry, or water and moist.

Air mass analysis may be defined as a careful study and analysis of preceding and present meteorological conditions and processes, particularly as regards the temperature and moisture properties of the air; the frontal structure, and their bearing on stability.

Precipitation is brought about by the lifting of air and the adiabatic cooling resulting from it. This lifting may be accomplished in several different ways: (1) by frontal action; (2) by insolational heating leading to instability and thermal convection; (3) by topography and (4) by convergence. All depend largely on the moisture content and the amount of cooling through lifting. Another very important characteristic of air is its initial stability, because on this condition depends a large part of our precipitation.

Air is said to be stable when it remains in or tends to return to its former level following displacement. If displacement results in a tendency to further movement away from its original position, the original condition is designated unstable. These conditions are different for dry and saturated air. An idea of whether a mass of air is stable or unstable may be obtained by comparison of the lapse rate of temperature of the particular air mass with the adiabatic lapse rate or rate at which air changes temperature with decrease of pressure. For dry air, the latter is 1° C. per hundred meters, about, and is commonly called the dry adiabatic. The adiabatic lapse rate of saturated air is less than that of the dry air because liberation of the latent heat of condensation has the effect of lessening the rate of temperature decrease due to expansion with increased altitude. Therefore, for dry air to be unstable, the lapse rate must be greater than the dry adiabatic and for saturated air the lapse rate must be greater than the saturation adiabatic.

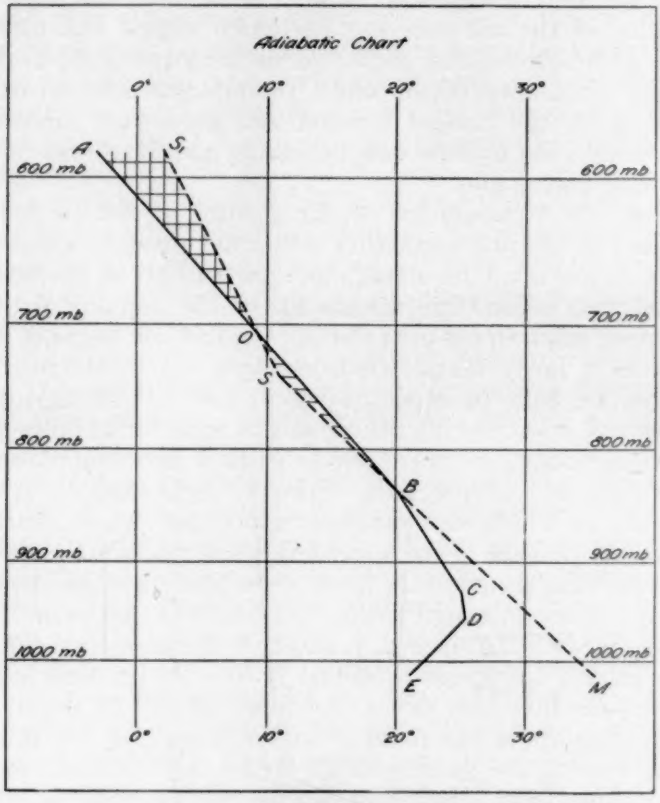
The conditions connected with stability and instability

have been fairly well understood for some years. Thermodynamic diagrams have been prepared from data obtained from kite and sounding balloon ascents, both of which gave temperature, humidity and pressure data in the vertical but which, however, were not available until some time after the forecasts were completed. These were used to show the stability of the air over the particular region but now we have such information available each morning from about twenty airplane stations which permits calculations of the stability for the current forecast and some very interesting and helpful deductions can be made, as illustrated in the following paragraph.

First the computation of the amount of surface heating required to produce instability under flat pressure conditions when no fronts are involved, more particularly in the warmer season; and second the calculation of the amount of lifting necessary when fronts are present. In the first instance when there is a fairly static condition with no fronts near the station, we have to depend on local surface heating for the creation of a force to lift the air and by such lifting to produce sufficient cooling in upper levels so that the temperature of saturation will be reached. Even in such cases, it is only possible to reach the condensation stage when potential instability prevails in the upper levels and this in turn depends on particular temperature lapse rates and moisture content. Let us assume an actual temperature distribution as indicated by the line *ABCDE* in Fig. 3, and that the maximum temperature during the afternoon will be 35° C. As the air is heated, the surface inversion below the point *B* will be wiped out. Any lifting above the point *B* will be along the dry adiabat *MBS*, leaving the particle of air cooler than the surrounding air at any level. In other words the air will be stable. But let us suppose that the saturation temperature will be reached at the point *S*, then any lifting of the air above that point will cause cooling along the saturation adiabat SS_1, with the result that the lifted particle of air will become warmer than the surrounding air at any level, resulting in instability and probably thunderstorms. In the second case, when fronts are present, the amount of lifting necessary to produce condensation can be extracted from a similar diagram.

In the first case results of very practical application can be secured. In the second, however, while it is possible to calculate from the thermodynamic diagram how much lifting will be needed to produce precipitation and instability, there

FIG. 3.



Stability diagram.

is no way known at present to obtain more than a general idea of how much actual lifting will ensue.

Temperature and moisture content are helpful in identifying the source of an air mass, but consideration must also be given to changes in both of them due to exposure to the different conditions in the region to which the air mass has moved. Evaporation and condensation as applying to the

moisture content and adiabatic changes as affecting temperature are the most important factors in changing the characteristics of air masses. In efforts to secure an index which will remain as constant as possible, with change of height and resulting change of temperature, equivalent potential temperature has been used to represent temperature; and specific humidity or mixing ratio has been employed to represent the moisture content. In brief equivalent potential temperature may be defined as the temperature a particle of air would have if it were lifted pseudo-adiabatically (approximately at the saturation adiabatic rate) until all its moisture had been removed, all the heat of condensation of water vapor being added to the air, and the sample of dry air then compressed to a pressure of 1,000 millibars (29.53 inches). Specific humidity is defined as the mass of water vapor per unit mass of moist air (grams of water vapor per gram of moist air).

Generally speaking, graphs showing the equivalent potential temperatures on a Rossby or similar diagram (see Fig. 4) are useful in determining the properties of an air mass and inferentially its origin. In brief it is found that, when the curve or line connecting the points representing equivalent potential temperatures is nearly vertical on the left-hand side of the diagram where the specific humidity is small, the air is dry at all levels, cold at the surface and warmer aloft. These properties are characteristic of polar continental air; see the Fargo graph of March 11, 1935, in Fig. 4. When the curve is nearly horizontal showing warm air at the surface and aloft and with high humidity at the surface decreasing with elevation, the characteristics are those of tropical ocean or tropical Gulf air; see the San Antonio graph of March 22, 1935, in Fig. 4.

In addition to the diagram, cross sections of the United States east and west and north and south (see Fig. 5) can be prepared each day showing equivalent potential temperatures (based on potential temperature and specific humidity) to assist in analyzing the air masses in the vertical and to give a more precise idea of the slope of the surfaces of discontinuity. A number of different methods of showing the characteristics of air masses have been tried but all methods essayed so far have drawbacks. If individual stations are used, we have

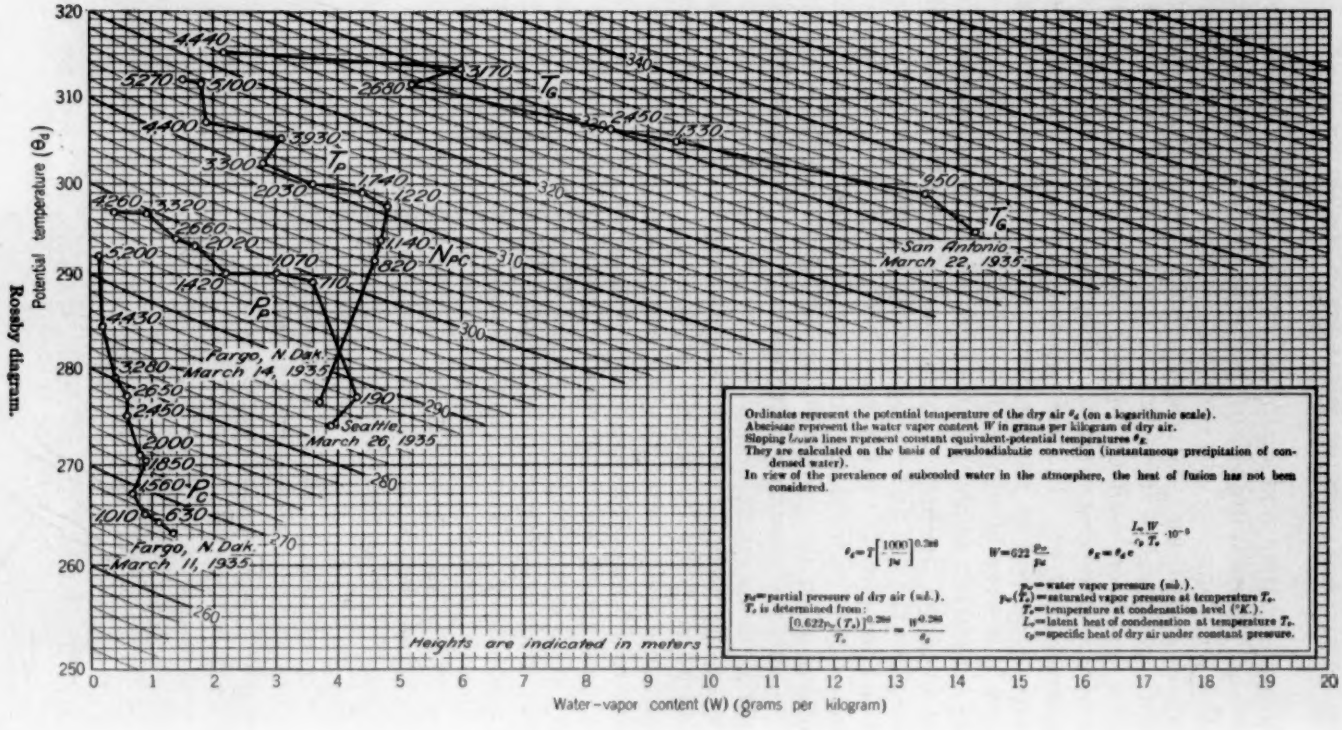
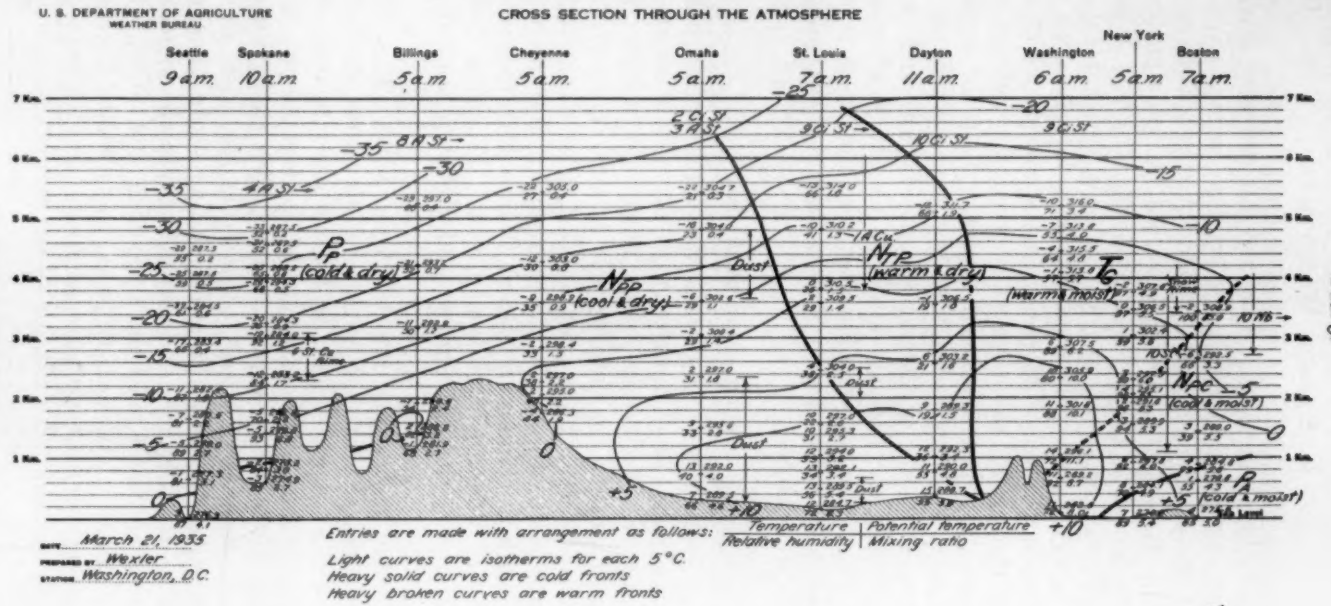

Potential temperature (θ_d)
Water-vapor content (W) (grams per kilogram)
Heights are indicated in meters
Rosby diagram.
Ordinates represent the potential temperature of the dry air θ_d (on a logarithmic scale).
Abscissae represent the water vapor content W in grams per kilogram of dry air.
Sloping broken lines represent constant equivalent-potential temperatures θ_E.
They are calculated on the basis of pseudoadiabatic convection (instantaneous precipitation of condensed water).
In view of the prevalence of subcooled water in the atmosphere, the heat of fusion has not been considered.
$\theta_d = T\left[\frac{1000}{p_d}\right]^{0.286}$
$W = 622\frac{p_w}{p_d}$
$\theta_E = \theta_d e^{\frac{L_v W}{c_p T_c}\cdot 10^{-3}}$
p_d = partial pressure of dry air (mb.).
T_c is determined from: $\frac{[0.622 p_w (T_c)]^{0.286}}{T_c} = \frac{W^{0.286}}{\theta_d}$
p_w = water vapor pressure (mb.).
$p_w(T_c)$ = saturated vapor pressure at temperature T_c.
T_c = temperature at condensation level (°K.).
L_v = latent heat of condensation at temperature T_c.
c_p = specific heat of dry air under constant pressure.
T_G
T_P
N_{PC}
P_2
P_0
San Antonio, March 22, 1935
Fargo, N Dak., March 14, 1935
Seattle, March 26, 1935
Fargo, N Dak., March 11, 1935

FIG. 4.



Atmospheric cross-sections.

FIG. 5.

blind spots between them. If charts for different levels are employed, we have blind spots between levels. We have come to the conclusion that airplane flights will have to be plotted by stations to be supplemented by some generalized scheme of presentation by levels or cross-sections. What the final method will be is subject to trial and careful tests. In all, however, air mass analysis deals largely with static conditions and in some degree with the mechanics of movement of the air at the time considered, as well as in the immediate past, but offers only indirect help for predicting the future. The next step was the development of kinematical methods for predicting the movements and changes in intensity of the pressure systems. Further advance will be in further increasing our knowledge of the physical laws of the action and interaction of air masses and their application to the weather charts.

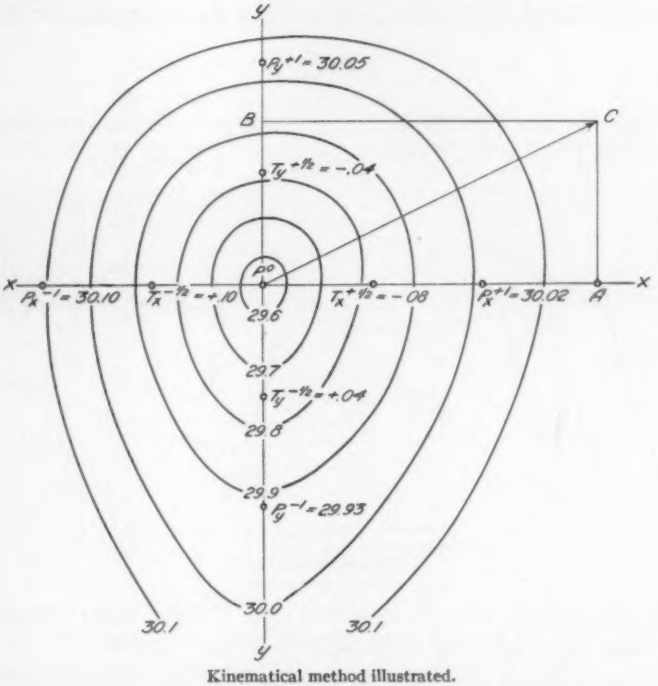
KINEMATICAL METHODS.

Up to very recent years the developments in practical forecasting have been mostly empirical so far as the map application was concerned, even since the introduction of the frontal model. In the last year or two, however, certain generalized methods have been applied to weather maps. A very important contribution was made by Petterssen in his paper entitled "Kinematical and Dynamical Properties of the Field of Pressure" followed by his "Practical Rules for Prognosticating the Movements and Developments of Pressure Centers."

Movement of Troughs, Fronts, Highs, Lows, Etc.—There is the fundamental fact that pressure is the most conservative meteorological element with which we have to deal in that it does not change with exposure of the instrument, the sky covering, nor with the wind, but only with the temperature for which correction is made. With this as a basis he developed formulas based on pressure and pressure changes for forecasting not only the movement, but also the increase and decrease in intensity and the deepening and filling of high and low pressure systems, troughs, wedges and fronts. He used pressure profiles and pressure tendency (3-hour changes) profiles to explain the operation of the terms that are used in

the quite simple formulæ which he derived through rather complicated mathematics. For example if we take the case of a trough which does not involve discontinuities of temperature and other elements and stripping it of its mathematical development, we find that coördinate axis may be drawn (see Fig. 6) through points of maximum and minimum curvature from which can be worked out the movement of

FIG. 6.

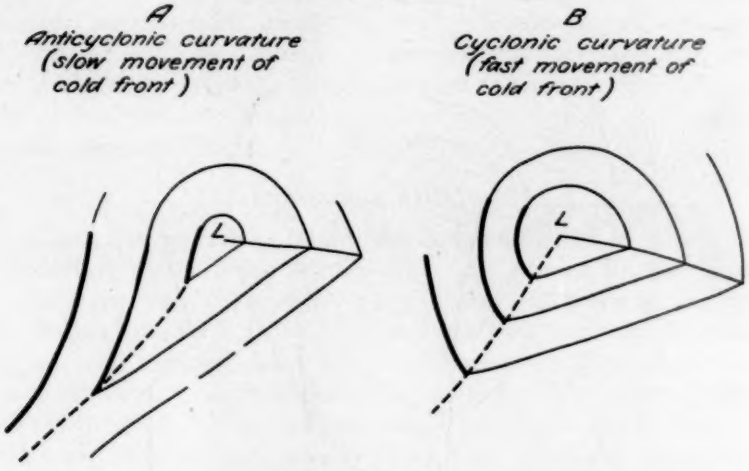


Kinematical method illustrated.

the trough. It is only necessary in the case of a trough to use the x axis and to select a distance unit such as P_0P_{+1} and lay off points ahead of the trough and behind the trough equal to this unit; then to take half unit distances. The formula is $-\dfrac{(T^{\frac{1}{2}} - T^{-\frac{1}{2}})}{P_1 - 2P_0 + P_{-1}}$ equals distance moved. In this formula $T^{\frac{1}{2}}$ is the tendency at a half unit distance ahead of the trough, $T^{-\frac{1}{2}}$ the tendency at a half unit dis-

tance behind the trough, P_1 the actual pressure 1 unit ahead of the trough, P_0 the pressure at the center of the trough, and P_{-1} the pressure 1 unit behind the trough. The numerator therefore gives the slope of the pressure tendency (change in 3 hours) profile, and the denominator gives the slope of the pressure profile. The solution gives the number of length units moved in three hours and it is necessary only to multiply by 4 to obtain the movement in 12 hours, and by 8 for 24 hours. For calculating the movement of a low center or a high center, it is necessary to work out the move-

FIG. 7.



Barometric profiles.

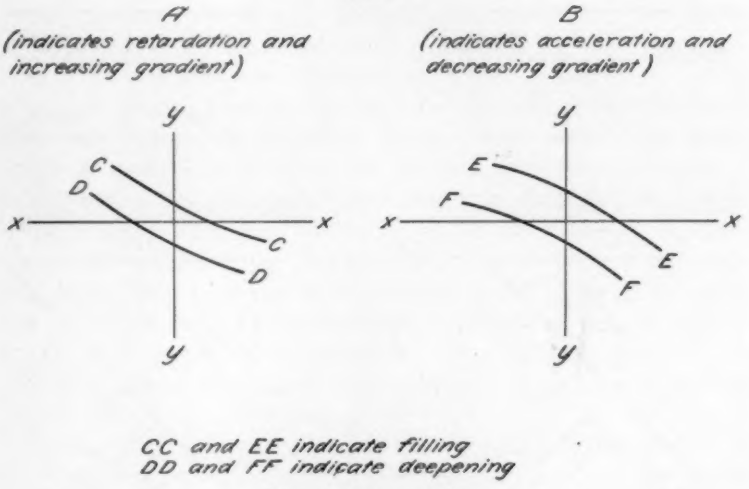
ment along both the X axis and the Y axis, after which the two may be combined as indicated in the figure.

A formula is also given for calculating the acceleration of the trough but, owing to the fact that several small quantities, namely pressure tendencies at successive three-hour intervals and the changes in them, which are subject to errors that may be almost as large as the quantities themselves, the results considering the data available are subject to large errors. The formulas are thoroughly rigorous and would give accurate results were the data free from inaccuracies. Fortunately there are in many cases means of using "neutral points" where the terms involving the small quantities above

mentioned vanish, thus permitting very good estimates to be obtained of the changes in intensity of the lows and highs and of their deepening and filling.

Change in Intensity.—From these formulas for discussing the low, the high, the trough, the wedge, etc., general rules have been developed for certain cases based on the shape of isobars and tendency profiles. If isobars behind a cold front, for example, have cyclonic curvature, the movement of the front will be rapid (see Fig. 7-B). If they are directed anticyclonically, the movement will be slow (see 7-A).

FIG. 8.



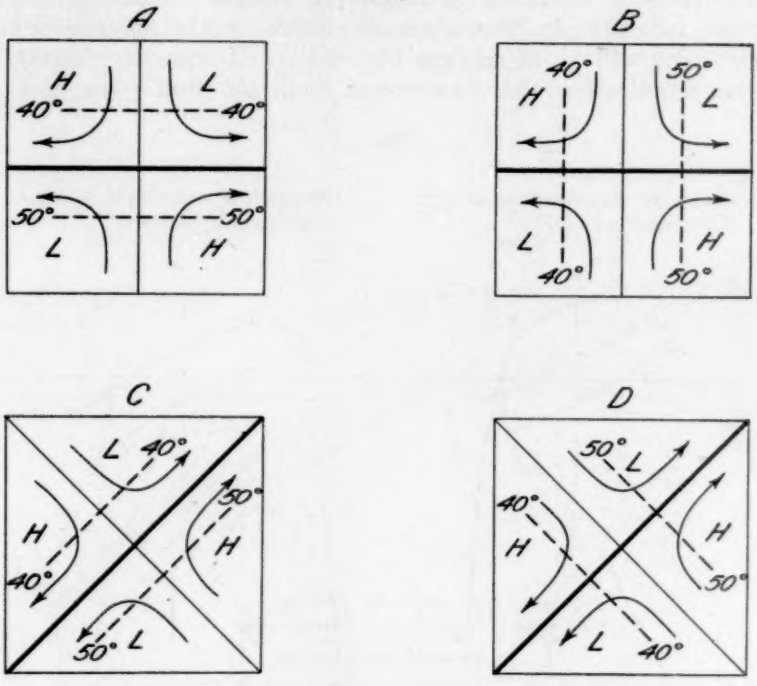
Pressure tendency profiles.

When the tendency profile cuts the *X* axis in the rear of the *Y* axis (see Fig. 8), deepening will result in a low, and if in advance of the *Y* axis, then filling will follow. The same principle applies to pressure tendency profiles in highs.

Fronto-genesis and Cyclo-genesis.—Formerly certain barometric types were known to be followed by the development of lows but the physical reasons underlying such developments were lacking or quite hazy. Now we are in a position to recognize in most cases, at least largely from a physical standpoint, the instances in which fronto-genesis or cyclogenesis will take place.

The difference in temperature between poles and equator furnishes the heat energy for the genesis and development of lows in temperate latitudes and, when deformation takes place, i.e., when temperature gradients are accentuated by the flow of tropical air northward and of polar air southward,

FIG. 9.



Curved lines are air trajectories. "H" is high pressure and "L" is low pressure. Broken lines are isotherms. Heavy lines are axes of deformation

Fronto-genesis as developed from pressure and temperature fields.

fronts develop (see Fig. 9*a* and 9*c*), and the stage is set for cyclo-genesis, which only takes place, however, when a cyclonic rotation is superposed on the temperature and pressure field and "curl" develops. The latter is indicated by falling tendencies along or just north of the axis of deformation, indicated by the heavy lines in the figures. Some

very interesting and instructive families of barometric and temperature patterns have been evolved, some of which lead to fronto-genesis and others to frontolysis. Two pair of these are shown in Fig. 9. It is to be noted that in *a* and *c* the isotherms (dotted lines) are parallel to the axis of deformation while in *b* and *d* the isotherms are at an angle of 90° to the axis of deformation. In the former fronto-genesis takes place because the wind streams called for by the pressure gradient increase the temperature gradient by bringing the isotherms closer together, while in the latter such is not the case. For a fuller discussion of these patterns, reference should be had to the original paper by Petterssen.

As we review the progress in forecasting, it is apparent that very definite and decided advances have been made since the World War due largely to the more complete and more numerous observations in the free air. The more complete understanding of the genesis and maintenance of the high and low pressure systems which we now think of in terms of air masses and interactions between them, together with a better knowledge of the physical processes involved in the causation of precipitation has been aided in great measure by the introduction of the Bjerknes cyclone model and in the last several years by Petterssen's kinematical methods of forecasting the movement and changes in intensity of the pressure systems and fronts.

While it is not yet possible to calculate mathematically the quantitative occurrence of precipitation, yet in many cases we can say qualitatively that amounts will be small or large. As stated, very definite progress has been made and there is every reason to believe that more progress will follow in this specialized branch of physics that holds for its devotees a fascination and allure second to none other.

Observations on Food Poisoning Organisms Under Refrigeration Conditions.—S. C. PRESCOTT AND L. P. GEER. (*Refrigerating Engineering*, Vol. 32, No. 4.) Outbreaks of illness due to the ingestion of foods which have become infected with certain types of bacteria have engaged the attention of public health workers for many years. The organisms of most serious import in this matter are probably *Clostridium botulinum*, the various species of *Salmonella* and certain species of *Staphylococcus*. Observations covering a period of three years were made in which suspected organisms or those known to be concerned with food poisoning have been inoculated into culture media or into various types of food materials and thereupon continuously held at various low temperatures for considerable time periods. It was found that the character of the food as well as the temperature at which it is kept affect the rate of increase or decrease of organisms. In media of distinctly acid character and in acid foods such as tomatoes, a sharp reduction occurred at temperatures as high as 50° F. However, in foods more nearly neutral in reaction, all the strains of *Salmonella* increased when kept at 10° C., indicating that this temperature cannot be depended on to inhibit these types. At 39°, 32°, and 19° F., decreases in numbers were observed with all organisms studied but storage at even the lowest temperature did not result in killing or inactivation of all the organisms. The conclusion reached from all data is that if foods subject to infection through manipulation or possibly unsanitary handling are refrigerated at temperature of 39° F. or lower the danger of food poisoning is greatly minimized. In the case of *Clostridium botulinum* refrigeration of properly prepared foods at temperatures below 50° F. will prevent the formation of toxin for extended but undetermined periods, and thus materially aid in the protection of the consumer. Spoilage of the food by other types of bacteria can, however, take place at 50° F.

R. H. O.

THE EXPERIMENTAL DETERMINATION OF THE VELOCITY OF RADIO WAVES.

BY

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ABSTRACT.

A radio station "A" sends out sixty short pulses a second; another station "B" at a distance of twenty kilometers is also sending out sixty pulses per second. By means of a phase shifter, the operator at B can send his pulses back to "A" at the exact instant of reception. Hence the station "B" acts as a reflector for the pulses. The operator at "B" sets his pulses in coincidence with those from "A" with the aid of an oscilloscope having a sixty cycle sweep. The operator at "A" measures the distance between the two groups of pulses seen on his oscilloscope. Since the sweep rate of the oscilloscope is known, the velocity can be calculated. For the medium-high frequency waves used, the velocity is considerably less than the velocity of light.

INTRODUCTION.

At the present time an extensive study of the ionosphere is being made both in the United States and abroad. Most of the measurements are based upon the general assumption that radio waves travel at the velocity of light. It is therefore of great importance to investigators to know whether the radio frequency pulses they send out actually travel at the velocity of light or at some other velocity. Frequently, in ionospheric measurements, the transmitter and the receiver are separated by many miles and, therefore, it is necessary to know whether ground waves travel at the velocity of light or whether they are slowed down due to their proximity to the earth.

In July and August 1936 the writers made a large number of ground wave velocity measurements between stations at West Virginia University and Fairmont State College which are 20.03 km. apart. The field apparatus was initially installed at Davis and Elkins College at a distance of 80 km. from the University but ground waves were found to be too weak for satisfactory measurements.

The system used is an adaptation of the Breit and Tuve pulse method of ionospheric measurement.[1] Essentially, the Breit and Tuve method consists of transmitting a continuous train of very short radio pulses which travel up to the various ionized layers of air and are reflected or refracted back to earth. The height of any layer is computed from the difference in time of arrival of the sky and ground pulses at the receiver, assuming the waves to travel at the velocity of light.

The only difference between the method of measuring radio wave velocity described herein and the Breit and Tuve method is that a second radio station takes the place of an ionized layer of air and starts a pulse back the instant one is received. Synchronization between the transmitting and receiving equipment at the two stations was automatically obtained as they were both supplied from the same 60 cycle power network.

The observations which have been taken thus far indicate the velocity of ground waves to vary between one half and two thirds the velocity of light. These experiments give no indication of the velocity of sky waves as it would be necessary to have a second radio station on a stratosphere balloon to make such measurements.

APPARATUS.

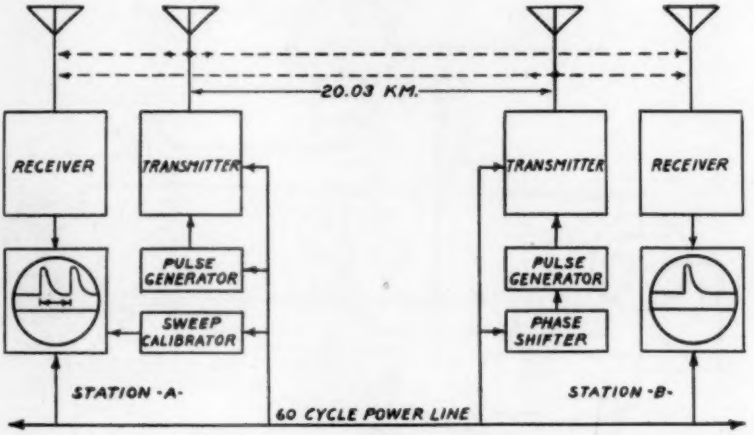
For convenience, the equipment at the University will be referred to as station "A" or the base station and the field equipment will be referred to as station "B." A block diagram of both stations is shown in Fig. 1. It will be noticed that the two stations are similarly equipped except that station "A" has an oscilloscope sweep calibrator and that the short pulse generator at station "B" is fed through a phase shifter.

The transmitter at "A" consists of a 2398 kc. crystal oscillator driving a 150-watt final r.f. amplifier. The grid of the amplifier tube is normally biased beyond cut off with full grid excitation applied. A pulse generator in series with the bias supply causes the amplifier grid to go positive once with each 60-cycle alternation, producing pulses 0.0001

[1] G. Breit and M. A. Tuve, *Phys. Rev.*, **28**, p. 554, 1926.

second in length. The transmitter at "B," which is also crystal controlled, was operated on 1614 and 2398 kc. with an input of 100 watts. Current fed antennae were used working against ground. The pulse generator at "B" may be made to fire in any time phase with respect to "A" by shifting the phase of the 60-cycle current which drives it.

FIG. 1.



Block diagram of the transmitting and receiving equipment. Dotted lines show the paths of the signals sent out by the two transmitters.

A diagram of the pulse generator and phase shifter at station "B" is shown in Fig. 2. Incidentally, this pulse generator has been found by the writers to be very suitable for regular ionospheric measurement as it is quite stable in operation and the adjustments are not critical.

During one half of the a. c. cycle, condenser *C* charges through a half wave rectifer to the peak voltage *V*-1, and the grid of the mercury triode (type 128) is biased negatively by voltage *V*-2 as the transformer windings are connected 180 degrees out of phase. Close to the peak of the next half cycle, voltage *V*-2, which has reversed its polarity, opposes the fixed grid bias on the mercury triode and allows it to fire. In the meantime condenser *C* is kept from discharging back throught the transformer by the half wave rectifier tube. As the mercury tube fires, condenser *C* discharges through

resistor R causing an instantaneous voltage drop across R. This voltage momentarily opposes the fixed bias on the final r.f. amplifier, allowing it to operate. The duration of the pulse is approximately equal to the time constant of the resistor-condenser circuit of the pulse generator. Pulses

FIG. 2.

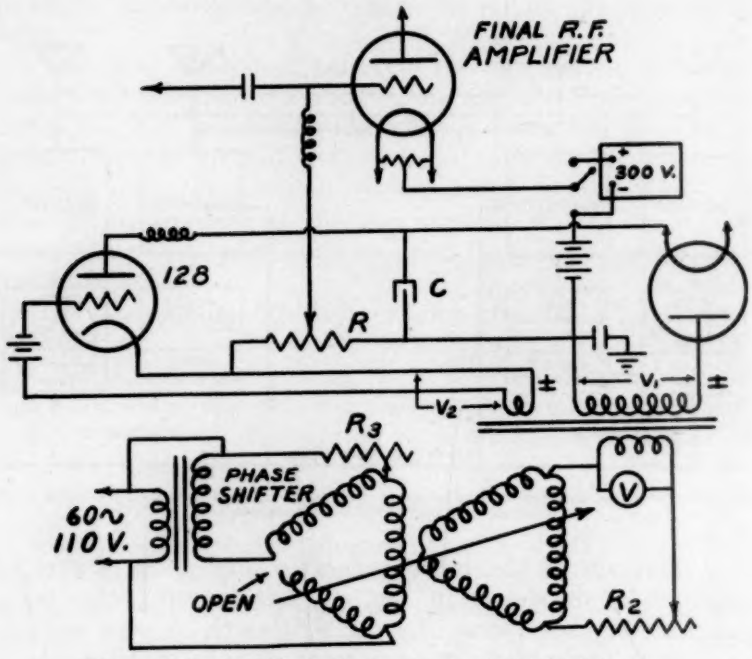


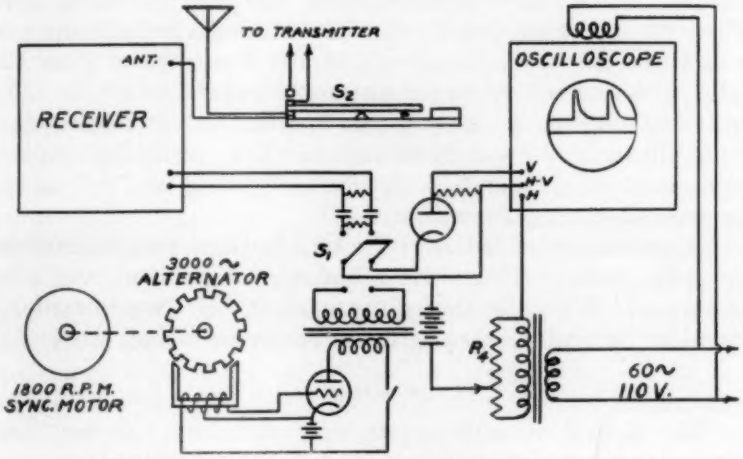
Diagram of the phase shifter and pulse generator used at the field station.

0.000005 second long are now being used by the writers for measuring the C region of the atmosphere. These pulses are generated by use of the circuit shown in Fig. 2.

In order to shift the phase of the pulse at station "B," a 220-volt, three-phase, delta connected phase shifter was used. As only single phase power was available, it was necessary to split the phase by a resistor and transformer network as shown in Fig. 2. Although the voltages obtained are far from being balanced, it is possible to keep the output voltage constant by adjusting resistor R-2 and observing the

output volt meter while the phase is being shifted. Once the correct adjustment is obtained, it is not necessary to adjust *R*-2 further because in the velocity measurements, only very small phase shifts are necessary and the output voltage does not vary appreciably with shifts of a few degrees.

FIG. 3.



Oscilloscope control equipment and sweep calibrator at the base station.

Standard commercial communications receivers were used at both stations. The receiving equipment at station "A" was separated from the transmitter by about 200 meters while both the receiver and the transmitter at station "B" were in the same room. It would have been advantageous to have had the receiver at "B" some distance from the transmitter but this was not attempted since the transmitter was used for both pulse and radiophone transmission.

A diagram of the receiving control equipment at station "A" is shown in Fig. 3. The output of the receiver is impressed upon the vertical deflecting plates of a cathode ray oscilloscope so that the electron beam is deflected vertically upward by the pulses. A double-pole-double-throw switch (*S*-1) makes it possible to shift the vertical plates of the tube from the receiver output to a 3000 cycle calibrating alternator which consists of a very small synchronous motor-driven

alternator and a one stage audio amplifier. The distance on the oscilloscope screen (about two cm.) between any two adjacent peaks of the 3000-cycle wave represents 1/3000 second. Both the transmitter pulses and the calibrating voltage wave maintain fixed positions on the screen since 60 cycle a.-c. voltage is used to obtain the horizontal sweep.

Switch *S*-2 (Fig. 3), which is operated by a foot pedal, has one set of contacts which close and one set which open when the pedal is depressed. The closing contacts operate a relay in the oscillator circuit of the transmitter while the opening contacts remove the antenna from the receiver. The receiving antenna is disconnected in order to reduce the signal input from the local transmitter. The receiving control equipment at station "B" is similar to that at "A" except for the calibrating alternator.

Communication between the two stations was maintained by radiophone. A separate telephone transmitter was used at station "A" while the transmitter at "B" was used both for velocity measurement and for communication.

TECHNIQUE.

The actual measurements are made as follows: The transmitters are placed in operation about fifteen minutes before measurements are to be made in order to allow the mercury vapor pulse tubes and other components to reach a stable operating temperature. The operator at station "A" observes his pulses as a fixed image on his oscilloscope (Fig. 3) although his receiver is tuned to the frequency of the transmitter at "B." This is possible because of the wide side bands and high signal strength of the local transmitter. The pulses from "A" are also observed by the operator at "B" as a fixed image on his oscilloscope due to the 60 cycle synchronization between the two points. After carefully noting the position of the front edge of the image, operator "B" depresses his foot switch which causes his own pulses to appear instead of those from "A." By adjusting his phase shifter he superimposes his pulses upon those from "A." As the two trains of pulses are observed individually, it is possible to bring them both in with the same volume, thus canceling out receiver time lag. The operator at "B" alternately

depresses and releases his foot switch at sufficient intervals to enable him to keep the two images superimposed on his screen. When this condition is obtained, a pulse leaves "B's" transmitting antenna at the exact instant that the corresponding pulse from "A" arrives at "B's" transmitting antenna. Although it is impossible to superimpose the pulses exactly, it is obvious that the errors will largely cancel out in several observations due to the equal probability of the setting being behind or ahead of the correct position.

Back at station "A" the operator adjusts his receiver so that the initial and return pulses produce equal deflections on his oscilloscope screen. When operation is on two different frequencies the foot switch is eliminated and the antenna is connected directly to the receiver so that both pulses can be seen simultaneously. Operation on the same frequency, however, necessitates the use of this switch since the oscillator of the transmitter produces a sufficiently strong signal to partially block the receiver and produce undesirable effects. The distance between the steep fronts of the two pulses is measured with a vernier caliper and recorded. *S*-1 is then thrown to the 3000-cycle alternator-amplifier and the distance between the peaks of the wave on that part of the screen where the pulses appeared is measured. The sweep voltage is usually adjusted so that one centimeter is equivalent to 1/6000 second. Under operating conditions the distance on the screen between the two pulses at "A" is somewhat more than one centimeter and can be measured quite accurately under favorable conditions.

Fortunately, the phase relation of the a.-c. lines in the two buildings which house the transmitting and receiving equipment is such that the pulses appear on the center portion of the 60-cycle sweep which is practically linear for time intervals of 1/3000 second. Had this not been the case it would have been necessary to shift the phase of the line at the oscilloscope in order to obtain the above condition. With the 3000-cycle alternator for calibration, the number of microseconds per millimeter were determined and this constant was used to determine the time interval between the two incoming pulses.

TABLE I.

Complete List of the Velocity Data Showing Time and Date at Which Each Reading Was Taken.

Time (A.M.)	Ground Wave Velocity (% velocity of light)	Time (A.M.)	Ground Wave Velocity (% velocity of light)
7-16-36		7-22-36	
7:50	65	4:15	58
8:30	62	5:50	59
8:50	61	6:15	60
9:00	65	6:50	57
9:10	63		Average 59
12:00	61		
	Average 63	7-24-36	
		4:15	61
7-17-36		4:30	58
7:50	70*	4:45	60
7:55	71*	5:00	61
8:00	64	5:15	59
8:05	62		Average 60
8:10	60		
8:15	58*	7-31-36	
8:20	62	2:40	54
8:25	57*	4:00	55
8:30	55*	4:20	54
	Average 62	4:45	55
		4:55	55
7-18-36		5:05	55
5:20	64	5:35	57
5:35	61	5:45	57
6:25	64	5:55	57
6:40	65	6:05	59
	Average 63	6:45	57
7-19-36		6:55	56
12:01	59		Average 56
12:30	52*		
1:00	55*	8-5-36	
1:30	57*	2:20	64
2:00	61	2:30	61
2:30	62	2:45	63
3:00	61	3:00	63
3:30	61	3:15	62
4:00	60	3:30	63
4:30	58	3:45	62
5:00	61	4:00	60
5:30	62	4:15	59
6:00	59	4:30	58
6:30	62	4:45	60
7:00	58	5:00	64
7:30	59	5:15	63
8:00	62		Average 62
	Average 60		
7-21-36			
5:00	62		
5:30	62		
6:00	60		
6:30	61		
	Average 61		

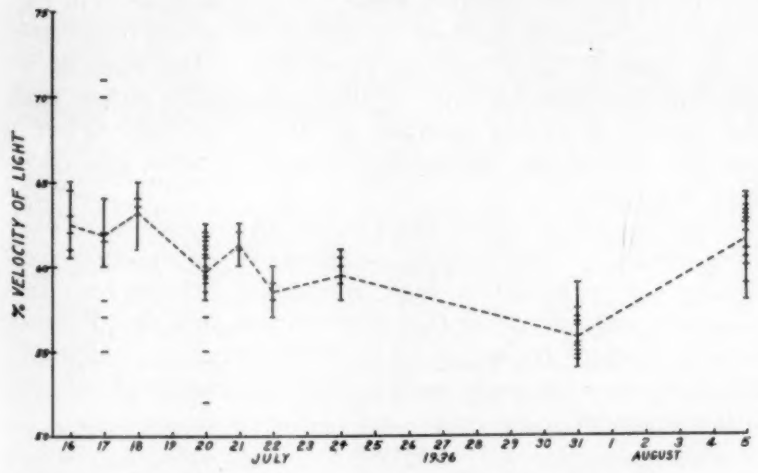
Values followed by asterisk are considered unreliable.

RESULTS.

The experiments were originally attempted with the two stations separated by a distance of 80 km. but it was found that the ground wave on 2398 kc. was insufficient for consistant measurements. The field station was then moved to a point 20.03 km. away and no further difficulty was experienced from lack of signal strength.

The base station was operated on a frequency of 2398 kc. and the field station on both 2398 and 1614 kc. No noticeable difference in velocity was observed so the field station was usually operated on 1614 kc. due to the greater ease in handling the equipment with the stations on different frequencies.

FIG. 4.



Curve showing daily variation of ground wave velocity. The dotted line connects the mean values.

All of the data which are shown in the table and in Fig. 4 were taken with the base station on 2398 kc. and the field station on 1614 kc. The runs were usually made in the early morning hours to escape the wide line voltage shifts which occurred at other times. No readings were discarded but the values marked with an asterisk are considered unreliable due to voltage shifts. They are shown in Fig. 4 to illustrate the errors which may arise from this source. Only on one

day July 31, was there any noticeable hourly trend but no conclusions could be drawn from the results of a single day. However, there is a distinct downward trend in the velocity between July 16 and 31, after which it turned upward.

In Fig. 4 the solid vertical lines represent the reliable limits over which readings were obtained and the short cross lines correspond to the individual measurements. During the first week of the tests the weather was unusually calm and generally hot. On July 30 the atmospheric conditions changed and considerable moisture was precipitated. Radio reception was unusually good on July 30 and 31, European short wave stations coming in with tremendous volume. At one A.M. on July 31 the ground wave pulse strength from station "A" was four times its normal value and by seven A.M. it was almost back to normal. It will be noticed in Fig. 4 that the velocity reached its lowest value approximately at the time of these unusual conditions. The data is insufficient for drawing any definite conclusions other than that there is an actual variation in the ground wave velocity and that the factors influencing radio in general also cause these variations.

Since our data was obtained by use of ground waves over short distances, the experiment gives no information concerning the velocity of high frequency sky waves. By increasing the power of the transmitters and the distance between stations the accuracy could be increased sufficiently to indicate hourly trends and to permit correlation of velocity with frequency.

ERRORS.

An examination of the data in Table 1 discloses the fact that the values of velocity taken only a few minutes apart sometimes differ by several percent. Since it is unlikely that the velocity actually changes by these amounts, the shifts are probably due to one or more of the following causes.

First: Voltage fluctuations and phase shifts in the 60-cycle power line connecting the two stations cause the pulses to drift and jump on the screen. During the hours between two and seven A.M. sudden shifts are usually absent in this locality but slight drifts sometimes occur. The apparent

changes in velocity during short periods of time were largely caused by this factor.

Second: Electrical interference, both man made and natural, which is received at the same time as the pulse will distort its appearance on the oscilloscope screen and heavy static will actually cause the pulse to shift on the screen.

Third: The lag in the receivers is not a constant but depends on the amplitude of the input signal. The lag in one of the receivers which was measured was found to be practically zero for very strong signals and the equivalent of twenty kilometers for very weak ones. This error was reduced to a minimum by adjusting the volume control so that the signal input from the two stations was the same, as indicated on the oscilloscope.

Errors due to the first two sources mentioned are not additive and so when the results of several measurements are averaged, the mean value has only a small probable error. The third one is always present to a slight extent and has undoubtedly been the source of considerable error in general ionospheric work. In these particular measurements careful adjustments reduced it to a practically negligible value. It is of interest to note that the simultaneous reception of a steady carrier signal and a pulse increases the time taken by the pulse to travel through the receiver and makes it desirable to avoid tuning the receiver to the exact frequency of the local transmitter. It is because of this effect that the two stations were usually operated on separate frequencies. Due to the wide side bands of the short pulse, it was possible to receive the local transmitter with the receiver tuned to the frequency of the other station. Investigations disclosed the fact that the receiver time lag was independent of detuning and so the use of the two different frequencies introduced no error.

CONCLUSIONS.

First: A method of measuring radio ground wave velocity is described which is capable of accurate results over distances as short as ten miles.

Second: The velocity with which radio waves travel along the ground is considerably less than that of light. This reduction in velocity is probably influenced by the

conductivity and dielectric constant of the earth and by the ionization of the atmosphere in and below the C region.

Third: The velocity of ground waves is not a constant. So far it has been impossible to obtain sufficient data for correlation between velocity and other phenomena but there is little doubt that conditions affecting radio communication in general also cause changes in the wave velocity.

Fourth: Virtual height measurements of low ionized regions, made with the transmitter and receiver several miles apart, will be appreciably in error if the ground wave velocity is assumed to be the same as that of light.

Fifth: The strength of the ground wave varies during periods of atmospheric disturbance. At one time the received signal was four times normal strength. During this period the measured velocity was a minimum.

Our thanks are due to President C. E. Albert of Davis and Elkins College for permitting us to set up a station in the physics laboratory at Elkins. We are likewise indebted to President Joseph Rosier and Professor H. F. Rogers for the many courtesies extended to us while the station was located at Fairmont State College, Fairmont, West Virginia.

THE REFRACTIVITY INTERCEPT AND THE SPECIFIC REFRACTION EQUATION OF NEWTON. I. DEVELOPMENT OF THE REFRACTIVITY INTERCEPT AND COMPARISON WITH SPECIFIC REFRACTION EQUATIONS.

BY

S. S. KURTZ, JR.,* AND A. L. WARD.†

ABSTRACT.

The significance of refractive index data and the relationship between the refractive index and the density of hydrocarbons are discussed. There are presented a new concept of refraction and a simple new constant, $n - d/2$, designated refractivity intercept, which is characteristic of each hydrocarbon series. The refractivity intercept is shown to represent a more constant relationship between the densities and refractive indices of the members of an homologous series of hydrocarbons than the usual equations for refractivity.

It is also shown that Newton's specific refraction equation represents the relationship between density and refractive index for sets of hydrocarbon isomers better than the Lorentz and Lorenz, Eykman, or Gladstone and Dale equations.

Finally, it is shown that the fundamental difficulty in past work on refractivity was the attempt to make one equation represent the effect of both temperature and constitution on the relationship between density and refractive index. For hydrocarbons, it is demonstrated that it is impossible for one equation to represent both the temperature and constitution effects.

I. INTRODUCTION.

This paper is primarily a plea for a change in point of view in regard to the significance of refractive index data and the relationship between the refractive index and the density of hydrocarbons.

That there is a relationship between the two constants has been evident since the properties were first studied. From Newton to the present time, investigators have attempted to develop and use equations which would harmonize the effect of temperature and constitution on the relationship of density to refractive index.

Although various equations which have been developed have been extremely useful in the study of hydrocarbons, it

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has been evident that none of them fulfilled all of the purposes for which attempts were made to use them. The rapidly growing importance of physical constants in the study of hydrocarbons has emphasized the weaknesses in the classical methods of treating density and refractive index data and justified a resurvey of the entire subject. At the same time the increasing volume of experimental data becoming available for pure hydrocarbons permits checking any equation against experimental data to an extent that was impossible until recently.

The present paper is a result of an extensive survey of the classical methods of relating density and refractivity index and of an intensive study of experimental data in an attempt (1) to derive a refractivity equation that would be more suitable and more convenient than any of the classical equations for characterizing homologous series of hydrocarbons by means of density and refractive index data determined at a fixed reference temperature such as 20° C., (2) to interpret homologous series relations in terms of the number and frequency of dispersion electrons, and (3) to derive an equation that would have theoretical significance and that would express the effect of temperature on refractive index as accurately as the empirical equation of Eykman. In part I of this paper item (1) only will be discussed.

Definition of Terms.

Refractive index (n) is defined as the ratio of the speed of light in space (vacuum) to its speed in a given substance. For approximate purposes the speed of light in air may be taken as equivalent to that in space. Refractive index for any given substance varies with the wave-length of light and the temperature. The symbols $n_D^{20°}$ = the refractive index for the D line of the Fraunhofer series (sodium) determined at 20° C. Density (d) is defined as mass per unit volume, specifically as grams per milliliter. Specific refractivity (r) is some function of refractive index divided by density. Molecular refractivity (mr) is specific refractivity multiplied by molecular weight (m).

II. HISTORICAL.

The earliest equation relating refractive index (n) and density (d) is that of Newton,[1] $(n^2 - 1)/d$ = constant. In deducing this equation Newton used a vectorial right triangle in which the hypothenuse had the direction of the refracted ray in the refracting substance, and a length proportional to the refractive index (i.e., to the reciprocal of the speed of the refracted ray).* One side of the vectorial triangle had the direction of the beam incident upon the refracting surface at grazing incidence, and a length equal to unity (i.e., to the speed of light in air). The third side of the triangle at right angles to the refracting surface is, therefore, equal to $\sqrt{n^2 - 1}$. Newton refers to the line $\sqrt{n^2 - 1}$ as the motion generated by the refracting force, and from the general laws of force deduces that $n^2 - 1$ = Force × Constant and hence that $n^2 - 1$ = Density × Constant. For the case of grazing incidence one may say that $\sqrt{n^2 - 1}$ = the component of the reciprocal of the speed of light that is at right angles to the direction of propagation.

Newton's original data are presented in Table I, which is a reproduction of the original. Column 1 gives the name of the substance; column 2 gives the refractive index (n) expressed as the ratio of the sines of the angle of incidence and the angle of refraction; column 3 gives $n^2 - 1$; column 4 gives the specific gravity relative to water as 1; and column 5 gives the numerical value of $(n^2 - 1)/d$.

Newton was gratified to find that for such a wide variety of substances, including air, organic liquids and minerals, the specific refraction varied only from approximately 0.4 to 1.4.

Laplace[2] derived the same equation from the emission theory of light, and added the concept that for any one compound the constant should be independent of external influence such as temperature and pressure. Laplace's interpretation of the Newton equation had a profound influence on the development of refraction theory since it

[1] Sir Isaac Newton, "Opticks," Book II, Part III, pages 245–251, Edition of 1717.

* Newton used the length of the hypotenuse to represent the "motion of the refracted ray," therefore his unit of "motion" is proportional to the refractive index, i.e., it is proportional to the reciprocal of the actual speed of light.

[2] Laplace, "Méchanique céleste" (4), **10**, 237 (1805).

directed attention to the change of refractive index and density of any one compound with change in temperatures and pressure.

TABLE I.

Newton's Specific Refraction Data Published in 1717.

The refracting Bodies.	*The Proportion of the Sines of Incidence and Refraction of yellow Light.*	*The Square of* BR, *to which the refracting force of the Body is proportionate*	*The density and specifick gravity of the Body.*	*The refractive Power of the Body in respect of its density.*
A Pseudo-Topazius, being a natural, pellucid, brittle, hairy Stone, of a yellow Colour.	23 to 14	1'699	4'27	3979
Air.	3201 to 3200	0'000625	0'0012	5208
Glass of Antimony.	17 to 9	2'568	5'28	4864
A Selenitis.	61 to 41	1'213	2'252	5386
Glass vulgar.	31 to 20	1'4025	2'58	5436
Crystal of the Rock.	25 to 16	1'445	2'65	5450
Island Crystal.	5 to 3	1'778	2'72	6536
Sal Gemmæ.	17 to 11	1'388	2'143	6477
Alume.	35 to 24	1'1267	1'714	6570
Borax.	22 to 15	1'1511	1'714	6716
Niter.	32 to 21	1'345	1'9	7079
Dantzick Vitriol.	303 to 200	1'295	1'715	7551
Oil of Vitriol.	10 to 7	1'041	1'7	6124
Rain Water.	529 to 396	0'7845	1'	7845
Gum Arabick.	31 to 21	1'179	1'375	8574
Spirit of Wine well rectified.	100 to 73	0'8765	0'866	10121
Camphire.	3 to 2	1'25	0'996	12551
Oil Olive.	22 to 15	1'1511	0'913	12607
Linseed Oil.	40 to 27	1'1948	0'932	12819
Spirit of Turpentine.	25 to 17	1'1626	0'874	13222
Ambar.	14 to 9	1'42	1'04	13654
A Diamond.	100 to 41	4'949	3'4	14556

In the period 1805 to 1863 it was shown that the constant of the Newton specific refraction equation was not independent of temperature.[3, 4] Many attempts were made to modify the

[3] Arago and Petit, *Ann. Chim. Phys.*, I, 1 (1816).

[4] Gladstone and Dale, *Philosophical Trans.*, 153, 321, 820 (1863).

formula. One of the more interesting of these attempts was that of Schrauf, [5] who proposed that n be replaced by the A of Cauchy's [6] formula $n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \text{etc.}$ The A in this formula is the hypothetical refractive index for a line of infinite wave length. No one succeeded in a modification of the Newton formula which was capable of giving a constant that was independent of temperature, and the formula as such was discarded * soon after the Gladstone-Dale paper was published in 1863. It is unfortunate that in the search for an equation that would be independent of temperature, the value of the Newton equation for other purposes was lost sight of.

Gladstone and Dale, [4] in addition to confirming the dependence of the Newton equation on temperature, presented a simple empirical equation, $(n - 1)/d$ = constant, and justified it on the grounds that for some 90 liquids, the constant in this equation decreased less rapidly with increasing temperature than did the constant of the Newton equation. The Gladstone-Dale equation ultimately achieved widespread use, second only to the Lorentz-Lorenz equation. (Vide infra.) Between 1863 and 1880, Landolt [8] did a great deal of work with the Gladstone and Dale "Molecular Refraction" $= m[(n - 1)/d]$ and established the fact that molecular refraction was roughly the sum of the atomic refractions of the constituents.

In 1880 the Lorentz-Lorenz specific refraction equation, $[(n^2 - 1)/(n^2 + 2)]1/d$ = constant, was simultaneously derived by Lorentz, [9] who started with Maxwell's electromagnetic

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[5] Schrauf, *Pogg. Ann.*, 119, 461 (1863).

[6] A. L. Cauchy, "Memoires sur le Despersion de la lumière," p. 62, A. G. Calue, Prague (1836).

* In 1888, Kettler [7] modified the formula to $(v - \beta)(n^2 - 1)$ = constant. In this equation v is the molecular volume and β is the limiting volume of the molecule as in Van der Waal's equation.

Many of the other equations may also be considered as modifications of the Newton formula. Thus the Lorentz-Lorenz and Eykman formulæ (vide infra) are the Newton formula divided by $(n^2 + 2)$ and $(n + 0.4)$ respectively.

[7] Kettler, *Wied. Ann.*, 33, 356 (1888), and 35, 662 (1888).

[8] F. Eisenlohr, "Spectrochemie Organischer Verbindungen," F. Enke, Stuttgart (1912).

[9] H. A. Lorentz, *Wied. Ann.*, 9, 64 (1880).

theory of light, and Lorenz,[10] who started with the undulatory theory of light. The specific and molecular refractions given by this equation increase slightly with increasing temperatures. Therefore, in the period 1880 to 1895 there was intensive investigation of these and many other specific and molecular refraction formulæ [8] until Eykman [11] presented his empirical equation $[(n^2 - 1)/(n + 0.4)]1/d$ = constant, which represents the relationship between refractive index and density accurately for any one liquid at various temperatures.

Notwithstanding the fact that the Eykman equation was shown to be less dependent on temperature than either the Lorentz-Lorenz or the Gladstone and Dale equations, the two latter equations have continued to dominate thought concerning the density and refractive index of organic compounds. The Lorentz-Lorenz equation in particular has been widely accepted because of its theoretical derivation and its close connection with the theory of dielectrics. Comparison of determined molecular or specific refractions with those calculated from the atomic refraction values has been the standard method of using refractive index data as an aid in determining the constitution of organic compounds.

An immense amount of work has been expended upon the derivation of the atomic constants to be used in calculating Lorentz-Lorenz molecular refractions. The best of the older values were given by Brühl,[12] but the values of Eisenlohr [13] replaced those of Brühl, and recently Hulst [14] has undertaken the task of revising these constants.

For carbon, hydrogen, and double bonds, the atomic refractions, according to these three authorities are given in the accompanying table.

TABLE II.

Atomic Refractions for Lorentz-Lorenz Formula and the D Line of Sodium.

	Carbon.	Hydrogen.	Double Bond.
Brühl	2.501	1.051	1.707
Eisenlohr	2.418	1.100	1.733
Hulst	2.590	1.025	—

[10] L. Lorenz, *Wied. Ann.*, **11**, 70 (1880).

[11] J. F. Eykman, *Rec. trav. chim.*, **14**, 185 (1895).

[12] J. W. Brühl, *Zeit. Phys. Chem.*, **7**, 140 (1891).

[13] F. Eisenlohr, *Zeit. Phys. Chem.*, **75**, 600 (1910).

[14] J. L. Van der Hulst, *Rec. trav. chim. Pay. Bas*, **54**, 518 (1935).

Assuming molecular refractivity to be an additive property, it follows that if the constitution and density of a compound be known, the refractive index can be calculated. Conversely, if the refractive index and constitution be known, the density can be calculated.

If molecular refractivity is really an additive property it should certainly be constant for a group of isomeric hydrocarbons. The excellent data that are available [15, 16, 17] for the isomeric heptanes offer an excellent opportunity for demonstrating whether molecular refraction is constant for a relatively simple case such as a group of saturated, non-cyclic, low molecular weight isomers. The data are shown in Table III.

TABLE III.

Deviation of Isomeric Heptanes from Average Specific Refraction Curves.

Compound.	$d\frac{20}{4}$.	$n\frac{20}{D}$.	Specific Refractions.			Deviation of Observed Refractive Index from Curves I, II and III in Fig. 1.		
			Lorentz and Lorenz.	Gladstone and Dale.	Newton.	Lorentz and Lorenz. (Curve I.)	Gladstone and Dale. (Curve II.)	Newton. (Curve III.)
2,2 dimethyl pentane....	0.6737	1.3823	0.3457	0.5675	1.3519	+0.0022	+0.0013	+0.0003
2,4 dimethyl pentane....	0.6745	1.3823	0.3453	0.5668	1.3503	+0.0016	+0.0008	−0.0001
2 methyl hexane.....	0.6787	1.3850	0.3453	0.5673	1.3528	+0.0016	+0.0011	+0.0005
Normal heptane.....	0.6839	1.3878	0.3449	0.5670	1.3539	+0.0011	+0.0010	+0.0008
3 methyl hexane.....	0.6870	1.3887	0.3440	0.5658	1.3515	0.0000	+0.0001	+0.0002
2,2,3 trimethyl butane...	0.6900	1.3894	0.3431	0.5643	1.3484	−0.0012	−0.0009	−0.0006
3,3 dimethyl pentane....	0.6930	1.3911	0.3429	0.5644	1.3491	−0.0014	−0.0009	−0.0003
2,3 dimethyl pentane....	0.6951	1.3920	0.3426	0.5639	1.3490	−0.0018	−0.0012	−0.0005
3 ethyl pentane.....	0.6984	1.3937	0.3423	0.5637	1.3493	−0.0022	−0.0014	−0.0004
Average.....	0.6860	1.3880	0.3440	0.5656	1.3507	0.0015	0.0010	0.0004

The molecular refractivity of the heptanes according to Eisenlohr's constants should be 34.526; according to Hulst's constants, 34.530. The average experimental molecular refraction = 34.442, with a maximum of 34.61 and minimum of 34.27. The difference (0.34) between the maximum and minimum molecular refraction is approximately 1.0 per cent.

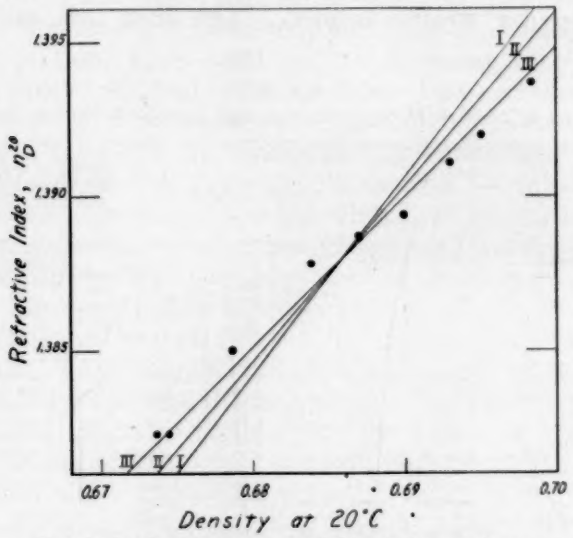
[15] G. Edgar, and G. Calingaert, *J. Am. Chem. Soc.*, **51**, 1546 (1929).

[16] C. P. Smyth, and W. N. Stoops, *J. Am. Chem. Soc.*, **50**, 1883 (1928).

[17] A. L. Ward, S. S. Kurtz, Jr., and W. H. Fulweiler, Chapter on Density and Refractive Index in "Science of Petroleum," Oxford University Press, London (in preparation).

and corresponds to 0.0044 in terms of refractive index. Since these density and refractive index data should be accurate to 1 in the fourth decimal place the data show definitely that molecular refractions are not strictly additive for these simple compounds. In Fig. 1, the curves are graphic representations of the three specific refractivity equations: Lorentz-Lorenz, Gladstone-Dale and Newton. In each case, the specific refractions were calculated from the experimental data for each of the heptane isomers. The average values are

FIG. 1.



Plot of refractive index versus density for the isomeric heptanes.

shown in Table III. The curves were drawn from the mean specific refractions for each of the three equations. The points are the experimental data [17] with densities plotted against refractive indices. If the equations represented the change in density and refractive index with change in structure, the points would fall on the curves. Curve I corresponds to the average Lorentz-Lorenz specific refraction of 0.3440. Curve II corresponds to the average Gladstone-Dale specific refraction 0.5656. Curve III corresponds to the average Newton specific refraction of 1.3507.

In order to simplify the following discussion of the slopes of the curves in Fig. 1, the following symbols will be used in addition to c, d, m and n already defined:

t = temperature; c = constitution;
con. = constant; var. = variable.

Since both the Lorentz and Lorenz and Gladstone and Dale specific refractions were developed to give constant specific refraction at various temperatures (t, var.) for any particular compound (c, con.), the slope of Curve I or II may be represented by the symbols $\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2}$. For the Lorentz-Lorenz specific refraction, Curve I, $\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2} = 0.64$; for the Gladstone and Dale specific refraction, Curve II, $\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2} = 0.57$; for the Eykman equation, which best correlates the change of refractive index and density with temperature, but which was omitted from Fig. 1, the slope $\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2} = 0.60$. The experimental data in Fig. 1 are for various compounds (c, var.) at 20° C. (t, con.). Since Curve III for the Newton equation represents the experimental data well, one may write for this curve the slope equation $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1}^{c_2} = 0.485$. Since for the heptanes the slope $\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2} = 0.60$ and the slope $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1}^{c_2} = 0.485$ it is clear that one and the same specific refraction equation cannot represent both the effect of (1) variation in temperature, and (2) variation in constitution, on the refractive index and density of the heptanes.

Similarly, it may be shown that the same generalization holds for hydrocarbons of higher molecular weight. Thus, it may be deduced from the small deviations of the Newton specific refraction for different groups of isomers, as shown in Table IX, vide infra, that the slope (0.485) of this equation remains practically constant. It has been shown elsewhere [17]

that for a wide variety of hydrocarbons the slope $\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2}$ also remains practically constant at the same value as for heptanes, i.e., 0.60.

Laplace assumed that the fundamental specific refraction equation would represent the relationship between refractive index and density with change in temperature, $\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2}$. Landolt and others in developing the concept of additive atomic refractions superimposed on the older concept of specific refraction the idea that the fundamental specific refraction equation would also represent the relationship between refractive index and density with changing structure, $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1}^{c_2}$, at least for compounds of closely related structure, such as, for example, saturated non-cyclic hydrocarbons.

Too much has been expected of the "ideal" specific refraction equation. Since specific refraction represents a relationship between refractive index and density it should not be assumed that any particular refraction equation applied for any conditions except those for which it is derived.

III. THE REFRACTIVITY INTERCEPT.

A plot of refractive index against density, Fig. 2, for the whole homologous series of paraffin hydrocarbons reveals the fact that an equation such as $n = 0.520 \times \text{density} + 1.0319$ more nearly represents the relationship between refractive index and density at 20° C. than does the Newton equation. In this equation the slope 0.520 equals $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1,\ m_1}^{c_2,\ m_2}$. Thus it is necessary to consider the effects of two variables on refractive index and density:

(1) Structure or Constitution (c), among a group of isomers.
(2) Molecular weight (m) in any homologous series.

Since the slope $\left[\frac{\Delta n_{t,\ m}}{\Delta d_{t,\ m}}\right]_{c_1}^{c_2}$ = approximately 0.485 and since the slope $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1,\ m_1}^{c_2,\ m_2}$ = approximately 0.520 it was decided to write an approximate empirical linear equation $y = mx + b$

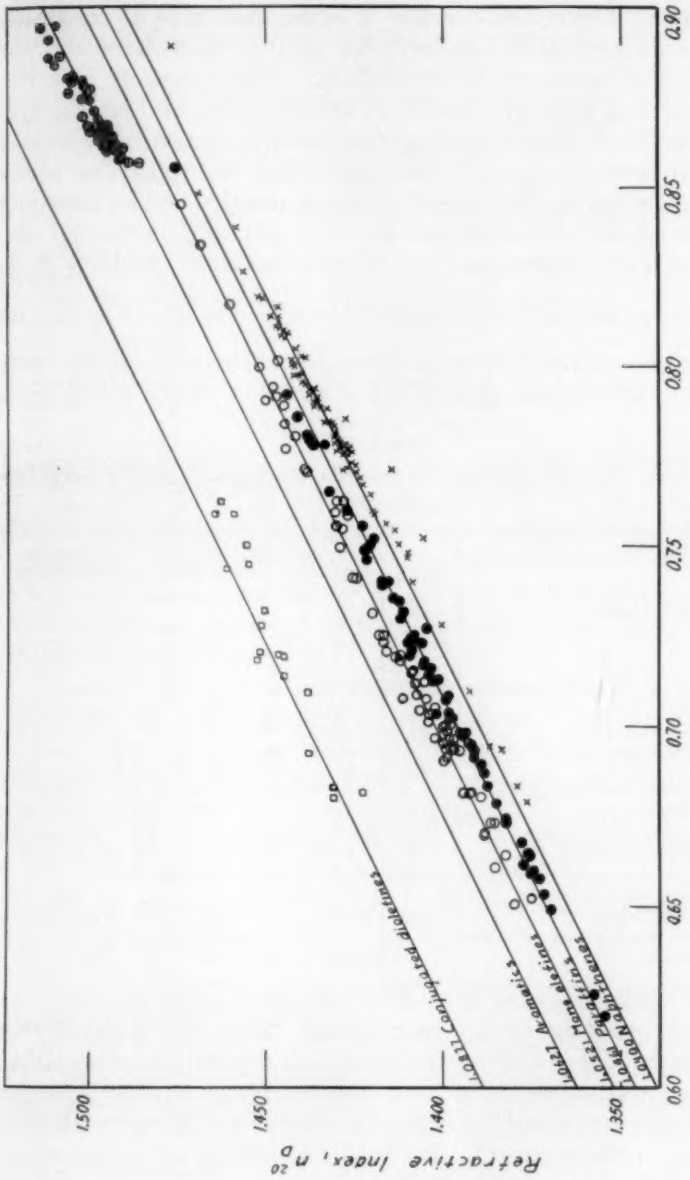

Refractive Index, n_D^{20}
1.500
1.450
1.400
1.350
DENSITY, d_4^{20}
0.60
0.65
0.70
0.75
0.80
0.85
0.90
Liquid paraffins
Liquid olefines
Liquid aromatics
Liquid naphthenes
Liquid carbohydrates

FIG. 2.

in which $y = n$; $m = 0.50$; $x = d$; and b = a constant. Such an equation serves both for groups of isomers and for homologous series of hydrocarbons. The constant b is the hypothetical refractive index at zero density, i.e., on a graph of refractive index plotted against density for an homologous series it is the intercept of the curve with the refractive index ordinate if the abcissa begins with zero density. The constant b is given by the equation $b = n - d/2$ and is named the "Refractivity Intercept." Unless otherwise specified it is understood that in this equation $n = n\frac{20}{D}$ and $d = d\frac{20}{4}$. The refractivity intercept is a constant characteristic of each homologous series as shown in Tables IV, V and X and Fig. 2.

TABLE IV.

Approximate Values for Refractivity Intercepts of Hydrocarbons at 20° C. for D Line (Sodium).

Series.	No. of Individual Hydrocarbons.	Refractivity Intercept $= n - \frac{d}{2}$.	Deviation from Average × 10^4.			Probable Error × 10^4.	
			Arithmetic Mean ±.	Maximum Plus.	Maximum Minus.	Mean.	Single Observation.
Paraffins	63	1.0462	14	35	51	1.4	12
Saturated monocyclic	81	1.0396	18	52	108	2.0	18
Saturated polycyclic	5	1.0285	33	46	89		
Aromatics	49	1.0629	20	53	57	2.4	17
Mono olefines	79	1.0521	20	53	46	1.8	16
Non conjugated diolefines	18	1.0602	43	93	98	7.7	32
Conjugated diolefines	27	1.0819	60	97	148	9.1	47
Cyclic unsaturates							
One double bond	55	1.0460	21	110	101	2.9	21
Two conjugated double bonds	8	1.0617	42	80	53	13.6	36

It should again be emphasized that the Refractivity Intercept is intended to give the simplest possible relationship between refractive index and density for homologous series of hydrocarbons and for sets of hydrocarbon isomers, all at a constant temperature.* Its field of usefulness is, therefore,

* The linear relation obtained on plotting refractive index against density for normal paraffins has been known for a long time (c.f. Engler-Höfer, "Das Erdöl," 1913, Vol. I, p. 112), but the practical value of the relation has not been realized.

TABLE V.

Most Probable Values for Refractivity Intercepts of Hydrocarbons at 20° C. for the D Line (Sodium).

Series.	No. of Individual Hydrocarbons.	Refractivity Intercept $= n - \frac{d}{2}$	Deviation from Average × 10⁴.			Probable Error × 10⁴.	
			Arithmetic Mean ±.	Maximum Plus.	Maximum Minus.	Mean.	Single Observation.
Paraffins	59	1.0461	12	24	26	1.2	10
Saturated monocyclic	74	1.0400	11	29	29	1.2	10
Aromatics	39	1.0627	14	30	29	1.8	11
Mono olefines	67	1.0521	16	29	29	1.5	12
Non conjugated diolefines	14	1.0592	23	47	49	5.1	19
Conjugated diolefines	12	1.0877	27	43	45	5.9	23
Cyclic unsaturates							
One double bond	49	1.0461	15	27	25	1.8	13
Two conjugated double bonds	5	1.0643	20	33	27	7.5	17

different from that of the Eykman equation which represents the relationship between refractive index and density with change in temperature.

There is some evidence that the characteristic frequency of vibration of the electrons in paraffin hydrocarbons decreases with increasing molecular weight, and that it is for this reason that the Newton equation does not apply for a whole homologous series. The refractivity intercept may, therefore, be considered as an empirical modification of the Newton equation which takes account of the decrease in frequency of vibration of the dispersion electrons with increasing molecular weight.

IV. CHANGE IN REFRACTIVITY INTERCEPT WITH CHANGE IN TEMPERATURE.

As stated above in the case of paraffins, the increase in refractive index with decrease in temperature is approximately 0.60 times the increase in density. For a further discussion see Ward, Kurtz and Fulweiler [17] by whom it was shown that this relationship holds for the other hydrocarbon series as well as for paraffins.

As was emphasized in the previous discussion, the differ-

ence in the slopes $\left[\frac{\Delta n_{c,\,m}}{\Delta d_{c,\,m}}\right]_{t_1}^{t_2}$ and $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1,\,m_1}^{c_2,\,m_2}$ of the curves precludes the possibility of any one equation representing both curves. The difference between 0.60, the temperature slope, and 0.50, the refractivity intercept slope, means that the intercept will decrease slightly with an increase in temperature. This decrease is given by the equation: Δ intercept $= 0.1\Delta$ density. The order of magnitude of the change is about 0.0006 to 0.0008 per 10 degrees Centigrade change in temperature. However, since the temperature coefficients for both density and refractive index have been established [17] there is little inconvenience in using the refractivity intercept with data published for temperatures other than 20° C.

V. REFRACTIVITY INTERCEPT OF PURE HYDROCARBONS.

The first test to which any proposed "constant," whether it be empirical or theoretical, must submit is the accuracy with which it conforms to the experimental data. For a group of paraffins of known high purity, the refractivity intercept represents the data with satisfactory accuracy. For example, the data for all of the heptanes give an average intercept constant of 1.0450 ± 0.0010, mean deviation, 0.0005. This is, of course, no proof of the conformity to the data of other paraffins, to say nothing of the constancy of the equation for hydrocarbons of other series. Since the equation is admittedly an approximation even for the paraffin hydrocarbons, a comprehensive survey of the accuracy and scope of the equation became imperative. The refractivity intercepts of a large number of hydrocarbons were, therefore, calculated. Such a test of a proposed constant for hydrocarbons can now be carried out with a thoroughness which was entirely out of the question with the limited amount of data available for hydrocarbons when the classical refractivity equations were formulated.

The data for hydrocarbons with which the refractivity intercept was checked had been selected from the literature as being the most accurate published values for all of the known members of the common hydrocarbon series in connection with a tabulation made for another purpose.[17]

In calculating a constant for such a large number of

hydrocarbons, the results become a test not merely of the validity of the constant but also of the accuracy of the data. Obviously with such a large mass of data, some of it is much more reliable than the rest. In the case of the common hydrocarbons in which several different investigators have reported closely agreeing data, it is an easy matter to select sound values. However, in the case of hydrocarbons for which one or more investigators have reported values that do not agree closely, the task of the compiler is much more difficult. For hydrocarbons for which only one set of values has been published, there is, of course, no possibility of selection. The values for 387 individual hydrocarbons of 9 series are shown in Table IV. Although the deviations from the averages may appear excessive, actually the percentage of the total number of hydrocarbons showing wide deviations was small. Considering the difficulties in the mere accurate determination of density and refractive index and the very much greater difficulties in the synthesis and purification of hydrocarbons, the agreement may be regarded as excellent. Nevertheless, it seemed desirable to study the results to determine to what extent the deviations were due to unsound data rather than to inherent deviations in the refractivity intercept. As a result of this study, the values for a number of hydrocarbons were eliminated and more probable average values for the different series were established. The most probable values are summarized in Table V and are shown graphically in Fig. 2. A discussion of the statistical and other considerations which lead to the elimination of the rejected data follows.

Paraffins.

Sixty-three different saturated non-cyclic hydrocarbons gave an average refractivity intercept of 1.0462, with a mean deviation of $\pm$ 0.0014. The probable error of the average ($r_0 = 0.6745\sqrt{\Sigma v^2/n(n-1)}$) was 0.00014 and of an individual determination was 0.0012. The maximum deviation was 0.0051. On a statistical basis, therefore, none of the values may be discarded.

A study of the values showed one deviation greater than 40, four greater than 30 and fourteen greater than 20. All of

the four with deviations greater than 30 were data published by one investigator for hydrocarbons for which no other values were found in the literature. It seems reasonable to discard these data, therefore. If this is done, the average value for 59 paraffins is 1.0461 with a mean deviation of ± 0.0012. The probable error of the average is 0.0001_2 and of a single observation is 0.0009_7. The maximum deviation is 0.0026.

Saturated Monocyclics (Naphthenes).

The average refractivity intercept of 81 saturated monocyclics was 1.0396 with a mean deviation of ± 0.0018. The probable errors of the mean and of an individual value were 0.0002_0 and 0.0018 respectively. The deviations of three hydrocarbons were greater than the statistical expectation. All three were cyclopentane derivatives for which only one investigator had reported values. Since density values published by reputable investigators for cyclopentane itself vary in the second decimal place, it must be concluded that the data for five membered series are in an unsatisfactory state.

If unconfirmed values for three other hydrocarbons are eliminated as being questionable, although within statistical expectations, the average for 74 saturated monocyclics is 1.0400 with a mean deviation of ± 0.0011. The probable errors of the mean and of an individual value are 0.0001_2 and 0.0010 respectively.

Saturated Di- and Polycyclics.

The data for these hydrocarbons are too meager to permit the establishment of a sound value. For three dicyclics, the average is 1.0298 with a mean deviation of ± 0.0014. The value for tricyclics is probably about 1.0200.

Olefins.

Because of the greater difficulty in preparing pure unsaturated hydrocarbons than saturated ones, it was to be expected that the deviations from the average would be larger in the case of the unsaturated hydrocarbons. This proved to be the case although the deviations were less than might be expected under the circumstances.

The average of 79 olefins was 1.0521 with a mean deviation of ± 0.0020. The probable errors of the average and of an individual value were 0.0001_8 and 0.0016 respectively. The maximum deviation was 53. This is within statistical expectations.

Of the 79 hydrocarbons, unsupported values for 4 showed deviations of greater than 40 and for 12 showed greater than 30. Eliminating these, the following values are arrived at:

No. of Olefins.	Average Refractivity Intercept.	Mean Deviation × 10^4.	Maximum Deviation × 10^4.		Probable Error × 10^4.	
			+.	−.	Mean.	Individual Value.
75	1.0520	18	37	38	1.6	14
67	1.0521	16	29	29	1.5	12

Unsaturated Cyclics with One Double Bond in the Ring.

For 55 hydrocarbons, the average was 1.0460 with a mean deviation of ± 0.0021 and probable errors of 0.0002_9 and 0.0021 respectively for the mean and for a single value. Of the 55, 6 showed deviations greater than 0.0050. Of these 6, 5 were cyclopentene derivatives. Eliminating the values for these six hydrocarbons leaves 49 with a refractivity intercept of 1.0461, a mean deviation of 0.0015 and probable errors of 0.0001_8 for the mean and 0.0013 for an individual value.

Unconjugated Diolefins.

Because of the known difficulties in preparing pure diolefins, it was expected that this series would show relatively wide deviations. This proved to be the case. It is particularly unfortunate, therefore, that the number of hydrocarbons available is so limited that the values for any constant of this character cannot be established with the accuracy of those discussed above. Nineteen hydrocarbons were listed. Because of the uncertainties of the positions of the double bonds in several of them, these may include several duplications. Of the 19, one was eliminated on statistical grounds. This left 18 with an average intercept of 1.0602, a mean deviation of 0.0043 and probable errors of 0.0007_7 and 0.0032 for the

mean and an individual value respectively. Eliminating the other four having the widest deviations left 14 with an average of 1.0592, a mean of ± 0.0023 and probable errors of 0.0005_1 and 0.0019.

Conjugated Diolefins.

The deviations are naturally worse in the case of the conjugated diolefins. Here, the individual deviations are very large. The average intercept of 27 hydrocarbons was 1.0819, with a mean deviation of 0.0060 and probable errors of 0.0009_1 and 0.0047. In attempting to arrive at the most probable value based on the best data available, two courses are open. The first is to eliminate the values showing the largest plus and minus deviations. This gives for 15 hydrocarbons an average of 1.0856, a mean deviation of ± 0.0033 and probable errors of 0.0006_8 and 0.0026.

In the case of this class of hydrocarbons, however, the common procedure does not appear to be justified. The possibilities of contamination with either a monolefin or an unconjugated diolefin or both are very much greater than the possibilities of contamination with anything which would give a higher intercept. Accordingly, it seems better to eliminate the lower values. This gives for 12 hydrocarbons an average intercept of 1.0877, a mean deviation of ± 0.0027 and probable errors of 0.0005_9 and 0.0023.

Unsaturated Cyclics, Two Conjugated Double Bonds.

Seven hydrocarbons with six carbon rings have an average intercept of 1.0617, a mean deviation of ± 0.0042 and probable errors of 0.0013_6 and 0.0036. Two of the hydrocarbons had low values. One was a methyl hexadiene with double bonds in uncertain positions. Although specific dispersion was low for two conjugated double bonds, it was too high for a non-conjugated hydrocarbon. The other was hexadiene (1,3). Its intercept is low enough to cast doubt on the purity of any sample for which data have been published. Eliminating cyclopentadiene and these two hydrocarbons leaves five hydrocarbons with an average intercept of 1.0643, a mean deviation of ± 0.0020 and probable errors of 0.0007_5 and 0.0017.

Aromatics.

For this series, 49 hydrocarbons were available. The average value was 1.0629 with a mean deviation of ± 0.0020. Although the mean deviation was not excessive, there were a number of unsupported values which showed rather wide deviations. Eliminating these left 39 hydrocarbons with an average intercept of 1.0627, a mean deviation of ± 0.0014 and probable errors of 0.0001_8 and 0.0011.

General Comments.

It will have been noted that the data eliminated, with the exception of the diolefins and certain of the cyclopentane derivatives, had no appreciable effect on the averages. Thus, the maximum change, due to elimination of data, in the averages for the paraffins, olefins, cyclic unsaturates and aromatics was 0.0002.

VI. SUMMARY OF EFFECT OF UNSATURATION ON REFRACTIVITY INTERCEPT.

The effect of introducing one double bond into the molecule of either an acyclic or a cyclic hydrocarbon is to increase the refractivity intercept by approximately 0.006. In the case of the acyclic compounds at least, the introduction of a second (non-conjugated) double bond has a very similar effect. The effect of conjugation appears to be much more pronounced in the case of acyclic than of cyclic compounds. Although the unsatisfactory data make it unsafe to accept this conclusion without further proof, it is of interest that specific refractive dispersion shows an analogous effect. The data are summarized in Table VI. The effect of unsaturation in mixed type compounds, such as some of the terpenes, is more complex and will not be discussed here.

VII. REFRACTIVITY INTERCEPTS OF HIGH MOLECULAR WEIGHT COMPOUNDS.

The data available for pure compounds are, for the most part, restricted to compounds of low molecular weight; therefore, the average values given in Tables IV and V are heavily weighted in favor of low molecular weight compounds.

The data in Table X show that for paraffins and olefins there is little shift in the value of the refractivity intercept with change in molecular weight. To obtain further infor-

TABLE VI.

Effect of Unsaturation on Refractivity Intercept and on Specific Refractive Dispersion.

Type.	Acyclic Hydrocarbons.				Cyclic Hydrocarbons.			
	Refractivity Intercept.	Change × 10^4.			Refractivity Intercept.	Change × 10^4.		
		For One Double Bond.	For Two Double Bonds.	For Two Conjugated Double Bonds.		For One Double Bond.	For Two Double Bonds.	For Two Conjugated Double Bonds.
Saturated	1.0461				1.0400			
One double bond	1.0521	60			1.0461	61		
Two double bonds	1.0592		129		—*		—	
Two conjugated bonds	1.0877			416	1.0643			243
	Specific Refractive Dispersion $\frac{n_g - n_C}{d} \times 10^4$				Specific Refractive Dispersion $\frac{n_g - n_C}{d} \times 10^4$			
Saturated	153				154			
One double bond	187	34			186	32		
Two double bonds	216		63		—*		—	
Two conjugated bonds	354			201	295			141

* Insufficient data to justify an average value.

mation relative to the refractivity intercepts of very high molecular weight compounds Table VII was prepared. This

TABLE VII.

Refractivity Intercepts for Hydrocarbons Having Very Large Molecules.

Compound.	Literature.	Temp.	Density.	Refractive Index n_D.	Refractivity Intercept.	
					16° C.	20° C.
Hydro-rubber	[18]	16	0.8585	1.4768	1.0476	1.0474
Hydrocyclo rubber	[18]	16	0.986	1.5264	1.0334	1.0332
Cyclo rubber	[19]	16	0.992	1.5387	1.0427	1.0425
Rubber	[18]	16	0.920	1.5222	1.0622	1.0620
Purified rubber	[20]	20	0.9237	1.5219		1.0601
Smoked sheet rubber	[20]	20	0.9217	1.5208		1.0600
Synthetic methyl rubber	[20]	20	0.9292	1.525		1.0604

[18] H. Staudinger, "Die Hoch Molekularen Organischen Verbindungen," Julius Springer, Berlin, 1932.

[19] H. L. Fisher, *Chem. Rev.*, 7, 119 (1930).

[20] International Critical Tables, McGraw-Hill Co., New York, Vol. II, 259 (1927).

table shows that the refractivity intercepts of rubber and related hydrocarbons having extremely long chain molecules are reasonably well in line with the refractivity intercepts for compounds in the gasoline boiling range. Hydrogenated rubber corresponds to a paraffin, hydrocyclo rubber corresponds to a saturated polycyclic compound, cyclo rubber corresponds to a cyclic unsaturated compound, and rubber itself to an unconjugated polyolefine. All of these hydrocarbons have molecules of such length as to attain colloidal dimensions and colloidal properties.[18] The agreement between the refractivity intercepts of such extremely high molecular weight and low molecular weight compounds is very encouraging and demonstrates that for any liquid single type hydrocarbon, the average refractivity intercept may be used without serious error.

The recent publication of Mikeska [21] provides data on a variety of mixed type compounds containing aromatic or naphthenic rings and long paraffin side chains. Part of these data are summarized in Table VIII. The distinction between the naphthene and aromatic ring compounds is quite clear, even though each ring has one or more long paraffinic side chains which cause the properties of the compound to be similar to the properties of a mixture of paraffinic and cyclic hydrocarbons.

TABLE VIII.

Average Refractivity Intercepts for Mixed Type Pure Hydrocarbons of High Molecular Weight According to Mikeska.[21]

Type of Compound.	No. of Compounds.	Approx. Average Formula.	Intercept at 25° C.
One benzene ring with saturated side chain	5	$C_{44}H_{82}$	1.0533
Naphthalene, diphenyl or 2 benzene rings with saturated chains	12	$C_{29}H_{43}$	1.0685
Saturated cyclics 1 ring and side chain	4	$C_{28}H_{56}$	1.0442
Dekahydro-naphthalene or dodekahydro diphenyl with side chains	4	$C_{31}H_{61}$	1.0442

VIII. COMPARISON OF DIFFERENT REFRACTIVITY EQUATIONS APPLIED TO PURE HYDROCARBON DATA.

It has been shown that the refractivity intercept is reasonably constant in each homologous series for compounds

[21] L. A. Mikeska, *Ind. Eng. Chem.*, **28**, p. 971 (1936).

having a wide range of molecular weights. It is, therefore, pertinent to determine whether any of the specific refraction equations yield constants which are equally as suitable as, or more suitable than, the refractivity intercept for characterizing homologous series.

In order to compare the different equations, Tables IX and X were prepared. In Table IX average specific refractions calculated for n_D^{20} by the equations of Lorentz-Lorenz, Eykman, Gladstone and Dale, and Newton, and by the refractivity intercept formula have been tabulated for 63 paraffins and 50 naphthenes. In Table X there is shown the effect of increasing molecular weight on the refractivity intercept and the four specific refractions.

If attention be confined to the paraffins in Tables IX and X, it will be seen that for a given set of isomers, the refractivity intercept and Newton equations show the smallest deviations. For a large difference in molecular weights, the refractivity intercept equation is much more constant than any of the older equations. This is because the slope was chosen as a compromise between the slopes for $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1,\ m_1}^{c_2,\ m_2}$ and $\left[\frac{\Delta n_{t,\ m}}{\Delta d_{t,\ m}}\right]_{c_1}^{c_2}$.

For olefins, the same two equations show the least deviations for large changes in molecular weight as shown in Table X. The advantage of the Newton equation over the refractivity intercept would be expected to become less if data for much higher molecular weight olefins were available. The data of Lebedew and Kobliansky[22] are of interest in this connection, since they provide data for polymers of isobutylene containing from 8 to 28 carbon atoms which show no trend in the refractivity intercept. These data are given in Table XI.

For the saturated cyclics and aromatics (Table X), the difference in the deviations of the different equations is much less than for paraffins and olefines, because the range of molecular weight for the cyclics is so small. The Gladstone-Dale equation shows the smallest deviation for both aromatics and naphthenes.

The data presented for the cyclic "homologous series" are limited to compounds with one ring, hence the increase in

[22] S. W. Lebedew and C. G. Kobliansky, *Ber.*, **63**, 103 and 1432 (1930).

TABLE IX.

Mean Deviations of Different Refractivity Equations as Applied to Paraffins and Saturated Cyclics.

Equation.		Lorentz-Lorenz. $\frac{n^2-1}{n^2+2}\cdot\frac{1}{d}$.			Eykman. $\frac{n^2-1}{n+0.4}\cdot\frac{1}{d}$.			Gladstone-Dale. $\frac{n-1}{d}$.			Newton. $\frac{n^2-1}{d}$.			Kurtz-Ward. $n-\frac{d}{2}$.		
Series.	No. of Hydrocarbons Averaged.	Ave.	Mean Dev.		Ave.	Mean Dev.		Ave.	Mean Dev.		Ave.	Mean Dev.		Ave.	Mean Dev.	
			Per Cent.	Equiv. n_D.		Per Cent.	Equiv. n_D.		Per Cent.	Equiv. n_D.		Per Cent.	Equiv. n_D.		Per Cent.	Equiv. n_D.
Paraffins																
C 5	2	0.3503	0	0.0	0.7659	0.02	0.0001	0.5710	0.03	0.0001	1.3457	0.05	0.0002	1.0444	0.02	0.0002
C 6	5	0.3473	0.29	0.0012	0.7568	0.28	0.0012	0.5687	0.26	0.0009	1.3482	0.13	0.0004	1.0452	0.10	0.0010
C 7	9	0.3440	0.34	0.0015	0.7554	0.27	0.0012	0.5656	0.25	0.0009	1.3507	0.12	0.0004	1.0450	0.05	0.0005
C 8	13	0.3432	0.46	0.0021	0.7546	0.50	0.0021	0.5660	0.39	0.0015	1.3592	0.65	0.0021	1.0447	0.17	0.0017
C 9	9	0.3404	0.65	0.0029	0.7493	0.64	0.0027	0.5622	0.45	0.0018	1.3547	0.39	0.0013	1.0451	0.12	0.0013
C 10	8	0.3406	0.27	0.0012	0.7504	0.25	0.0010	0.5638	0.22	0.0009	1.3591	0.17	0.0006	1.0465	0.07	0.0007
General average including 17 compounds C 11 to C 35, data from ref. (17)	63	0.3413	0.98	0.0043	0.7517	0.77	0.0034	0.5641	0.50	0.0020	1.3576	0.54	0.0018	1.0462	0.13	0.0014
Saturated Cyclics																
50 hydrocarbons C 5 to C 10	50	0.3305	0.70	0.0035	0.7302	0.57	0.0025	0.5494	0.53	0.0022	1.3326	0.49	0.0017	1.0386	0.19	0.0020
25 cyclohexane derivatives, C 6 to C 10, data from ref. (17)	25	0.3305	0.38	0.0019	0.7308	0.32	0.0014	0.5505	0.28	0.0012	1.3395	0.39	0.0014	1.0399	0.09	0.0010

TABLE X.

*Change in Refractivities with Change in Molecular Weight.**

Equation.			Lorentz-Lorenz. $\frac{n^2-1}{n^2+2}\cdot\frac{1}{d}$.			Eykman. $\frac{n^2-1}{n+0.4}\cdot\frac{1}{d}$.			Gladstone-Dale. $\frac{n-1}{d}$.			Newton. $\frac{n^2-1}{d}$.			Kurtz-Ward. $n-\frac{d}{2}$.		
Series.	Ave. No. of C Atoms.	No. of Hydrocarbons Averaged.	Ave.	Per Cent.	Equiv. n_D.	Ave.	Per Cent.	Equiv. n_D.	Ave.	Per Cent.	Equiv. n_D.	Ave.	Per Cent.	Equiv. n_D.	Ave.	Per Cent.	Equiv. n_D.
Paraffins...	5	2	0.3503			0.7658			0.5709			1.3457			1.0444		
	33	2	0.3323			0.7382			0.5582			1.3728			1.0479		
Difference	28		0.0180	5.3	0.0240	0.0276	3.7	0.0160	0.0127	2.2	0.0091	0.0271	2.0	0.0065	0.0035	0.34	0.0035
Olefins.....	5	2	0.3555			0.7801			0.5837			1.3909			1.0547		
	20	2	0.3374			0.7483			0.5653			1.3858			1.0522		
Difference	15		0.0181	5.2	0.0232	0.0318	4.2	0.0175	0.0184	3.2	0.0126	0.0051	0.37	0.0013	0.0025	0.24	0.0025
Saturated Cyclics.	5.4	10	0.3340			0.7339			0.5509			1.3210			1.0367		
	8.6	10	0.3295			0.7293			0.5499			1.3408			1.0398		
Difference	2.8		0.0045	1.4	0.0065	0.0046	0.63	0.0027	0.0010	0.18	0.0008	0.0198	1.5	0.0052	0.0031	0.28	0.0031
Aromatics..	7	3	0.3348			0.7491			0.5720			1.4234			1.0630		
	15	5	0.3367			0.7517			0.5710			1.4254			1.0618		
Difference	8		0.0019	0.57	0.0033	0.0026	0.35	0.0019	0.0010	0.18	0.0009	0.0020	0.14	0.0006	0.0012	0.11	0.0012

* Data from ref. (17).

TABLE XI.

Refractivity Intercepts for Polymers of Isobutylene.

Formula.	d_4^{20}.	n_d^{20}.	Refractivity Intercept.
$(C_4H_8)_2$	0.7195	1.4112	1.0515
$(C_4H_8)_3$	0.7600	1.4306	1.0506
$(C_4H_8)_4$	0.7944	1.4482	1.0510
$(C_4H_8)_5$	0.8176	1.4601	1.0513
$(C_4H_8)_5$	0.8146	1.4577	1.0504
$(C_4H_8)_6$	0.8340	1.4684	1.0514
$(C_4H_8)_7$	0.8455	1.4739	1.0512

molecular weight and density in these compounds is mainly arrived at by adding side chains, which are essentially paraffinic in nature. It is, therefore, not unreasonable that the refractivity intercepts of the naphthene and aromatics with large side chains should tend to shift toward the value for paraffins. This is also shown by the data of Mikeska.[21]

In any comparison at constant temperature (except for two pentanes) that has been made on hydrocarbon data, the Lorentz-Lorenz equation has shown the widest deviation of any of the five equations.

IX. SPECIFIC FIELDS OF USEFULNESS OF CLASSICAL EQUATIONS.

Before continuing with the discussion of the refractivity intercept, it may be well to review the specific advantages of the Lorentz-Lorenz, Eykman, Gladstone and Dale, and Newton equations. It has been shown that the Newton equation is the best of these equations for expressing either $\left[\frac{\Delta n_{t,\,m}}{\Delta d_{t,\,m}}\right]_{c_1}^{c_2}$ or $\left[\frac{\Delta n_t}{\Delta d_t}\right]_{c_1,\,m_1}^{c_2,\,m_2}$ and that the Lorentz-Lorenz equation is the least valuable for either purpose. Of the three commonly used equations, however, there are other purposes for which the equations are used. Their relative values for two of these are summarized as follows:

(1) The Eykman equation is the most useful of the classical equations for expressing the relationship between refractive index and density with changing temperature $\left[\frac{\Delta n}{\Delta d}\right]_{t_1}^{t_2}$.

(2) The Lorentz-Lorenz equation is the more useful of the classical equations for bringing out the relationship between optical and electrical properties.

(3) The Gladstone and Dale specific refraction and the Newton specific refraction may both be used to classify naphthas roughly according to hydrocarbon type. The Gladstone and Dale specific refraction is much better for this purpose than the Lorentz-Lorenz or Eykman specific refraction, but is not so good as the refractivity intercept.[17]

The reasons for (1) and (3) have been given above. A discussion of the basis for (2) would be beyond the scope of this paper.

X. PRACTICAL USE OF THE REFRACTIVITY INTERCEPT IN THE STUDY OF HYDROCARBONS AND HYDROCARBON MIXTURES.

The refractivity intercept has a wide range of usefulness because it provides a constant characteristic of each homologous series of hydrocarbons, a constant which is practically independent of boiling point or molecular weight. This paper is primarily concerned with the relation of the refractivity intercept to specific refraction and dispersion theory, therefore, the practical uses of this constant will be treated very briefly.

a. Selection of Data.

In compiling tables of data on the properties of pure hydrocarbons it is necessary to have criteria by which to distinguish between reliable and unreliable data. The data for the isomeric heptanes make it clear that one cannot depend entirely upon the calculated molecular refraction for this purpose. Calculation of the refractivity intercept does not by itself prove that data are accurate, even though the intercept may coincide with the average value for the homologous series in question. However, wide deviations in the intercept from the average for the particular type of hydrocarbon, normally indicate errors of some kind. In practice, the refractivity intercept has proven very valuable in calling attention to: (1) errors in the transcription of data, (2) improper correction for temperature, (3) uncertainty on the part of the original author concerning the purity of the compound, (4) unsound data.

b. Evaluation of Physical Data for Compounds Not Isolated or Synthesized Previously.

In confirming the structure of a new hydrocarbon and establishing the probability of its purity, the refractivity intercept is valuable, particularly if the properties of compounds isomeric with the new compound are available.

For such purposes it may sometimes be advisable to use the average intercept for the hydrocarbon isomeric with the one in question, rather than the average for the whole series. This should be done only if the intercepts of five or more isomers are accurately known.

c. Qualitative Analysis of Organic Liquids.

The refractivity intercepts of the lower alcohols, mercaptans, ethers, sulfides, ketones, organic halides, etc., are in general less than 1.000, whereas hydrocarbons, with the possible exception of some high molecular weight polynuclear naphthenes, are above 1.010. Therefore, the refractivity intercept provides a ready means for distinguishing between hydrocarbons and compounds containing appreciable proportions of oxygen, sulfur, or halogen.

In the case of hydrocarbon mixtures, the refractivity intercept may be used to distinguish between saturated cyclic and aromatic compounds, both of which have relatively high density and refractive index. As shown by Ward, Kurtz and Fulweiler [17] a large number of naturally occurring naphthas of high density have *low* refractivity intercepts. One may, therefore, conclude that most natural naphthas which have a high density contain much more saturated cyclic than aromatic material.

Two examples of qualitative analysis follow:

Example No. 1. A California gasoline [23] yielded a narrow cut having the following properties:

Boiling point	= 79.2° C.,
Density, d_4^{20}	= 0.7378,
Refractive index, n_D^{20}	= 1.4091,
Refractivity intercept	= 1.0402.

[23] J. B. Hill, L. M. Henderson, and S. W. Ferris, *Ind. Eng. Chem.*, **19**, 128 (1927).

This cut clearly owes its high density to saturated cyclic compounds. All the cuts of this naphtha were either naphthenic or paraffinic in quality.

Example No. 2. An aviation fuel yielded cuts of which the following is typical in quality:

Boiling point	= 185° C.,
Density, d_4^{20}	= 0.8718,
Refractive index, n_D^{20}	= 1.5020,
Refractivity intercept	= 1.0661.

This naphtha is distinctly aromatic in type.

d. Quantitative Analysis of Hydrocarbons.

In the analysis of hydrocarbon mixtures physical properties such as density, refractive index, specific refraction, aniline point, etc. have frequently been used to estimate the proportion of two constituent types, such as paraffins and naphthenes, in the binary mixture remaining after the removal of aromatics and olefines. It is possible by means of the refractivity intercept to determine graphically the proportion of three constituent types such as paraffins, naphthenes and aromatics in naturally occurring naphthas, or aromatics, noncyclic olefins and cyclic olefines in cracked naphthas. The method depends upon plotting refractivity intercept against density for pure compounds, thus obtaining a physical property triangle suitable for graphical analysis of the unknown three component mixture. Master graphs of this type are prepared for each of 7 cuts of fixed boiling range. A direct plot of refractive index against density gives a physical property triangle which is too elongated for practical use. Dispersion plotted against density for such constituents also yields a physical property triangle of approximately the proper form, but the refractivity intercept-density triangle is more convenient and more accurate.

A complete description of a method for analyzing naphtha which uses (1) fractional distillation, (2) chemical treatment and (3) physical property triangles will be given by Kurtz and Headington.[24]

[24] S. S. Kurtz, Jr., and C. E. Headington, Paper to appear soon in *Ind. Eng. Chem.* or *Ind. Eng. Chem., Anal. Ed.*

XI. THE ELECTRONIC INTERPRETATION OF THE REFRACTIVITY INTERCEPT.

An approximate equation $n^2 - 1 = B/(v_0^2 - v^2)$ which has been discussed by Richtmeyer [25] and used by Drude and Erfle [26] may be used to estimate the number and frequency of the vibrating electrons in refracting substances. On the basis of a preliminary investigation, it appears that the difference in the refractivity intercepts of paraffins and naphthenes is owing to the fact that there are approximately 13.8×10^{22} dispersion electrons per gram in naphthenes, and 14.0 to 14.3×10^{22} dispersion electrons in paraffins. The number of electrons per bond appears to be approximately 1.066 for saturated hydrocarbons, and the frequency of vibration appears to be essentially the same for a paraffin and naphthene of the same density. According to this point of view, the refractivity intercepts of paraffins and naphthenes are closely related to their carbon and hydrogen ratios since the number of bonds per gram decreases as the proportion of hydrogen decreases.

In the case of olefins and aromatic hydrocarbons, both the number and frequency of the dispersion electrons are much less than in saturated hydrocarbons, but the denominator in the approximate equation decreases more rapidly than does the numerator and therefore the net effect is a relatively high refractive index for a given density in the case of olefins and aromatics.

As pointed out by Houstoun,[27] the Newton equation may be derived as a special case of the above approximate dispersion equation. Consideration of the Newton equation from a dispersion point of view makes it seem reasonable to account for observed deviations from Newton's specific refraction equation as being caused by small changes in the apparent frequency of the dispersion electrons, particularly with changes in temperature and molecular weights.

The second part of this paper presenting a more detailed study of this interpretation of the refractivity intercept and the Newton equation will be published in an early issue of this journal.

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[25] F. K. Richtmyer, "Introduction to Modern Physics," McGraw-Hill, New York, 1928, pp. 111–121.

[26] H. Erfle, *Zeits. f. physik. Chemie*, **61**, 399–421 (1908).

[27] R. A. Houstoun, "Treatise on Light," Longmans Green & Co., New York, 1930, p. 429.

SUMMARY.

1. It is shown by a thorough statistical study of data for paraffin hydrocarbons that Newton's specific refraction equation expresses the relationship between refractive index and density for sets of hydrocarbon isomers, whereas the equations of Gladstone and Dale, Lorentz and Lorenz, and Eykman do not.

2. The fundamental reason for the failure of the Lorentz-Lorenz, Eykman, and Gladstone-Dale equations to express the change of refractive index with density for hydrocarbon isomers is shown to be the difference in the slopes of the refractive index density curves which express the effect of (*a*) temperature and (*b*) constitution.

3. It is shown that the "Refractivity Intercept," defined as Refractivity intercept $= n - d/2$, is a useful constant for classifying hydrocarbons according to homologous series, and for analyzing hydrocarbon mixtures.

4. A preliminary electronic interpretation of the refractivity intercept and the Newton specific refraction equation is presented.

Acknowledgment. The authors wish to acknowledge the encouragement of Dr. T. G. Delbridge, of the Atlantic Refining Company, in connection with the publication of this work, and the assistance of Mr. P. F. Dougherty in making many of the calculations summarized in Tables VIII and IX.

EULOGY OF WATT.*

BY

H. W. DICKINSON, Esq., of London,

Past President, The Newcomen Society of England.

Why are we commemorating this week the Bicentenary of the birth of James Watt? The answer is that he was one of the world's geniuses. When the wee mite came into the world on January 19, 1736, in the small seaport town of Greenock on the Firth of Clyde in Scotland, what promise was there that he would make, as he did, the greatest individual contribution the world has known to the development of the steam engine? The chance of his surviving, let alone becoming famous, must have seemed small when we remember that five brothers and one sister born before him had died in infancy. Small wonder that he was a delicate child and that his mother lavished on him the utmost care and attention. As a boy he showed no aptitude for schooling—he was considered "dull and inapt." However, we know that it is not always the brilliant boy who takes the prizes at school, who turns out the successful man. One subject only aroused young Watt's interest and that was mathematics. As a youth he spent most of his spare time in the workshop of his father who was by trade a wright, or as we, outside Scotland, would say a carpenter and builder, but as is not unusual in a small town he had other irons in the fire and carried on the trade of shipwright, shipchandler and general merchant. Apart from this he was a public-spirited man who was so much esteemed by his fellow citizens that he became a Bailie and Treasurer of the Burgh.

When the time came for Jamie to decide on a career, attracted probably by the nautical instruments that came

* Read by Colonel C. E. Davies, Hon. Secretary for the United States, The Newcomen Society, at the dinner held under the auspices of The Franklin Institute on the occasion of the observance of the Two Hundredth Anniversary of the birth of James Watt, Tuesday, January 21, 1936.

into his father's workshop for repair, and his own predilection for handicraft, he decided he would like to become a mathematical instrument maker. No such trade was carried on at that date, 1755, in Greenock nor what is more astonishing in Glasgow, so young Watt went to London, the Mecca of instrument makers. There was then no stage coach on the road and the usual way of travelling was on horseback. Watt, like other folk who made the single journey, had to buy a saddle horse at the start and sell it at the other end. On arrival, he had difficulty in finding a master to take him in, but eventually he found one in the person of John Morgan of Cornhill in the City. Here he spent a year, working every hour of the day he could to improve his craftsmanship and his knowledge of the trade. In 1757 he returned to Greenock with the intention of setting up in business for himself. The story of his having been thwarted in his intention by the Trade Guilds of Glasgow has been, like the report of Mark Twain's death was, "greatly exaggerated." The outcome of it was that he did not immediately set up a shop in the city but did so by permission of the authorities in the precincts of the old College of Glasgow, which was outside the jurisdiction of the city.

The turning point of his career occurred when the College sent to him for repair a model of the Newcomen or atmospheric steam engine. He succeeded in putting it to rights, although the well-known instrument maker Sisson had previously failed in doing so, but not until he had mastered its mode of action and had found by experiment what a "steam eater" it was.

For months he tortured his brain to find out a remedy for this, till one Sabbath morning in 1765 when out on Glasgow Green to take the air, the idea of condensing the steam outside the cylinder in another vessel flashed into his brain. Consider for a moment what were the stages that had been passed through. Denis Papin in 1690 had made a cylinder and piston apparatus; in the bottom of the cylinder he placed a little water and boiled it to steam so raising the piston; he then allowed the apparatus to cool and the piston descended raising a weight—nothing of a workable engine in this you will agree! Thomas Newcomen boiled the water in a separate vessel and

admitted steam as wanted to the cylinder where he condensed it with a jet of water and the piston was forced down by the pressure of the atmosphere; the cycle could be repeated 15 or 20 times in a minute. Now we have a proper engine but oh! so wasteful in fuel! James Watt condensed the steam in a vessel separate from the cylinder and so diminished the heat losses that the fuel consumption was only about a third of that of the common engine. Now at last the engine could start on a career of world-wide usefulness! The biological analogy of cell division will be obvious.

The first few years after the invention of the condenser was a heartbreaking time for Watt who, knowing nothing of engine construction and but little of the millwright's art, found great difficulty in reducing his ideas to practice. He received financial help from Dr. John Roebuck, a great captain of industry who was interested because he wanted improved means of unwatering his coal mines in Linlighowshire, but soon after helping Watt to patent the engine in 1769, became financially straitened and could give no further help. Meanwhile, Watt had his living to earn and turned to surveying and civil engineering. It is not too much to say that, if he had continued to practice this profession, he would have attained to the front rank in it.

On a journey to London and back in 1768 to take out his patent, Watt made the acquaintance of the "princely" Matthew Boulton of Birmingham, perhaps the best known manufacturer of his day in England. This was the second great turning point in Watt's career for it led eventually to Boulton taking over Roebuck's share in the patent after the latter's bankruptcy. But a fresh difficulty appeared—five out of the fourteen years of the duration of the patent had run their course and it was obvious that the time left would be all too short to recoup any outlay upon it. The remedy was to apply for a new patent or for an extension of the old one; the latter course was decided on and in 1775 an extension for twenty-five years was obtained from Parliament. It was for this period that the most celebrated partnership in industrial history—that of Boulton and Watt—was entered upon.

The firm did not themselves supply engines but acted much like consulting engineers, furnishing drawings, some

important parts like the valves, and sending an erector on the job. The engine itself was built at the client's expense in the way usual at that time, i.e. like a house is built: masonry from one place, timber from a second, cast iron parts from a third and so on. Payment for the engine was made on a royalty basis—one-third of the value of coal consumed by a common engine doing equivalent work. Cornwall, where the cost of pumping was so high because the fuel had to be imported, was the most fruitful field for exploitation and the doings there of the firm and of their faithful and stout-hearted henchman William Murdock reads like an epic!

Hitherto the engine had been nothing more than a giant pump but everywhere there were calls for much more extended applications, viz., for industrial purposes generally, and to do this the engine must be made rotative, in other words it must turn shafting for millwork. This far-reaching development was achieved by Watt from 1781 onwards and since then the progress of the steam engine for power purposes of all kinds has been that of a "rushing mighty wind." This development carried with it many ancillary inventions: application of the crank; double action of the piston; the parallel motion; expansive working of steam; centrifugal governor control and engine indicating. In fact this was the most brilliant inventive period of Watt's career.

As the name and fame of the engine spread abroad, it naturally excited the cupidity of small men who infringed the patent. After litigation extending over six years with the worst offenders and at a cost of upwards of £10,000, the Law Courts upheld the patents at every point. The judgment was given very appropriately when the extended patent was about to expire in 1800. When this time came and with it the close of the partnership it was with heartfelt relief that Watt retired from the hurly-burly, leaving his sons and Boulton's son to carry on the business under the new style of Boulton, Watt & Co.

When we reflect upon Watt's intellectual output, we are amazed when we are told that he was never of strong physique and that he suffered till well past middle age from attacks of sick headache that prostrated him for days together especially when unduly worried. Watt was no hero: he was cautious,

unenterprising, self-depreciatory; he was pessimistic in the extreme, he hated business and shunned disputes. He was in very truth the antithesis of Boulton and this is probably the reason why they got on together so well.

Watt lived in retirement for nineteen years enjoying his *otium cum dignitate* but keeping active mentally. One of the tasks, unfinished however, that engaged his attention was the invention of sculpturing machines. He died on August 25, 1819, full of years and honours at the ripe age of 84, and was buried in Handsworth Church, Warwickshire, where there is a statue by Chantrey to his memory. Indeed no inventor or engineer before or since has received such public recognition as has James Watt.

Looking back over his career we can say without hesitation that he was above all fortunate in his association with Boulton. Without the latter it is all too probable that Watt's invention would have been filched from him and although his specification enrolled in the Patent office would establish that he was the inventor of the separate condenser steam engine, yet without Boulton the environment would not have been created wherein he could follow up with the equally brilliant inventions relating to the rotative engine nor would he have attained the substantial fortune that he enjoyed in his declining years.

Great as the changes that have taken place in the steam engine since his day—we keep in mind always that even the steam turbine to function most economically embodies Watt's condenser—we can affirm safely that no one has made a greater contribution to it, for good or ill, than has James Watt.

A New Spectrophotometer and Some of Its Applications.—J. L. MICHAELSON AND DR. H. A. LIEBHAFSKY. (*General Electric Review*, Vol. 39, No. 9.) An instrument of high precision has been devised by Professor A. C. Hardy and developed by the General Electric Co. for industrial application. The spectrophotometer consists essentially of a double-prism monochromator, a photoelectric photometer, and a graphical recorder. The monochromator is of the double-prism type which insures a high degree of spectral purity. It is equipped with bilateral slits that are automatically adjusted for a wave-length band of 10 millimicrons. The photometer combines the polarization method of photometry with a photoelectric balancing scheme in a manner that eliminates such possible sources of error as light source characteristic and phototube and amplifier sensitivity. The light source is a coiled filament tungsten lamp. Because of the high precision obtained the instrument may be employed in the solution of a great many problems in diverse fields of industrial control, color specifications, and research. With the spectrophotometer, the effect on an applied organic finish of such factors as heat, light, ultra-violet radiation, humidity, and surface grease can be quantitatively determined. Also its use in determinations of chemical substances has many advantages over the old procedure by the visual comparison of an unknown with a standard solution with or without the aid of a colorimeter. The determination of titanium in the absence of interfering elements is the simplest type of application. These are only a few of the many possible applications to chemical problems. The instrument can usually be of service in problems involving colored substances. Even elements whose ordinary compounds are colorless come within the range of the spectrophotometer as new colored compounds containing them are discovered.

R. H. O.

STEAM AND THE RAILROADS.*

BY

WILLIAM CARTER DICKERMAN,

President, American Locomotive Company.

Our material progress, since the days of James Watt has been measured by the development of our natural resources and of our means of communication.

Put another way, we might say that commerce and trade and business have been promoted and upheld by industry and transportation. By transportation I mean *the railroads*.

Lord Macaulay had railroads in mind when he wrote these time-honored words:

"Of all inventions, the alphabet and printing press alone excepted, *those inventions which abridge distance* have done most for civilization."

If you were to ask whether the railroads have contributed mightily, my reply would be an unhesitating affirmative. And I would follow with the statement that *Steam* has been an all-important factor. Why? Because without Steam there would have been no railroads! And without the steam engine, Steam would have been of little use. Which gets us back again to James Watt—an altogether appropriate starting point under the circumstances of the present distinguished international occasion.

However, it is my purpose, during the brief moments allotted me tonight, to present to you contrasts, facts, trends, and evidence as to the contribution Steam has made to the railroads; rather than allow myself the indulgence of dwelling upon the philosophies of Civilization.

The advent of Steam was really contemporaneous with the beginnings of the American Republic: Watt was working

* Address delivered at the dinner held under the auspices of The Franklin Institute on the occasion of the observance of the Two Hundredth Anniversary of the birth of James Watt, Tuesday, January 21, 1936.

on the manufacture of his engines in 1787 while the Constitutional Convention was sitting here in this very city of Philadelphia. In 1784, two stage coaches sufficed for all the transportation business by land between Boston and New York. The south-bound coach started from Boston at 3 A.M., and arrived at Providence, forty-four miles away, at 10 P.M.—provided everything went well. Forty-four miles in nineteen hours.

As late as 1843, before there was yet any transcontinental railway, we find record in the famous Senate debates on the Oregon Bill, of Senator McDuffie of South Carolina ridiculing the idea of ever admitting Oregon into the Union, *because it would require ten months for the Representative to travel to the national capital and return.*

In 1859, the overland pony express began to run from St. Joseph, Missouri, to San Francisco. In 1861, it carried President Lincoln's message over 2,000 miles in seven days and seventeen hours, probably the quickest time on horseback ever made in this or any other country. Colonel Cody, known the world over as "Buffalo Bill," was one of the pony express riders in this service, whose equipment included 500 horses, 190 stations, 200 men for the care of the stations, and 80 riders, each of whom rode 33⅓ miles, using 3 ponies on his route. Letters were written on thin tissue and the postage was 5 dollars per letter.

TWO JOURNEYS: 1736 AND 1936.

However, I have said that James Watt is our starting point in tonight's discussion, and I wish to say further that contrast often best tells a story!

Greenock, on the Firth of Clyde in Scotland, the town of which you have been hearing so abundantly during the three days of this Bicentenary Celebration, is situated 23 miles from Glasgow; and Glasgow in turn is just 401 miles from London.

On January 21, 1736, two hundred years ago today, had James Watt's father wished to journey to London with his distinguished 2-day-old infant son, it would have taken him a day to reach Glasgow over the Scotch roads of the period, and probably twenty more days to arrive at London. A

total of three weeks on the road, travelling every day. Steam and the railroads had not then been harnessed together, to serve humanity.

And now the contrast!

By coöperation of the Associated British Railways, with offices at New York, I am enabled to give you an accurate picture of how Watt's father and the infant son could have made the same journey *on January 21, 1936*, this very day.

They could have left Greenock on a train over the lines of the London, Midland & Scottish Railway at 8:50 o'clock this morning, and arrived 41 minutes later at Central Station in Glasgow. There the elder Watt would have had ample time to read an early edition of this morning's *London Times* carrying perhaps an Associated Press dispatch from the United States speaking of these meetings here today at Philadelphia in honor of the birth of the distinguished infant son.

At 10 o'clock this morning, the two would have boarded at Glasgow the world-famous express train: "The Royal Scot," whose journeys in the United States three years ago in connection with the Century of Progress Exposition aroused such wide interest.

Over an historic route of the "L. M. S.," the father and son would pass through Carlisle, "The Gateway to Scotland," located on the Scotch-English border, and also pass through Lancaster, Crewe, Stafford, and Rugby. Luncheon would be served on the train, as the southbound and northbound "Royal Scots" pass each other at full speed just north of Preston.

And finally, our party of two would have arrived at Euston Station, London, *at 5:40 o'clock this afternoon*, 401 miles in 7 hours and 40 minutes, at an average overall speed of 52 miles an hour, *by Steam*. On the journey, they would have climbed to an altitude of 1,000 feet above sea-level.

The cost of the trip from Greenock to London, 424 miles, would have been 4 pounds, 6 shillings and 5 pence for first-class travel; or 2 pounds 11 shillings and 11 pence for third-class. The distinguished infant son, James Watt, would have travelled free, being under three years of age.

At the present rate of exchange ($4.94 to the Pound Sterling), the first-class fare would have cost $21.35, and the

third-class $12.82. "The Royal Scot" does not carry second-class accommodations.

I congratulate my friend, Sir Josiah Stamp, G.B.E., Chairman and President of the Executive Board of the London, Midland & Scottish Railway, on the performance which "The Royal Scot" daily is rendering. Moreover, I have cause to suspect that the two Watts would wish to join in these congratulations, because for them more than for anyone else, did the contrast of Steam and the Railroads *versus* 18th Century Travel come closest home.

Contrast often best tells a story!

GEORGE STEPHENSON.

Immortal in railroad history is the name of George Stephenson, the British mechanical engineer whose work on locomotives, from 1814 on, brought final success in the performance in 1829 of his engine "The Rocket," at the Rainhill Competition Trials near Liverpool. The trials, as most of you know, were to decide for the Liverpool & Manchester Railway whether their recently completed line was to be operated by stationary engines with rope traction or by steam locomotives. Stephenson's "Rocket" won and locomotives were decided upon.

Before Stephenson's locomotive, it sometimes took longer to transport a cargo of cotton from Liverpool to the mills in Manchester, a distance of thirty miles, than it did to bring the cargo across the Atlantic on a sailing vessel.

A new era in transportation had arrived.

AMERICAN TRAVEL IN 1825.

I want to give you something of the atmosphere of travel in America, just prior to the introduction of the steam locomotive:

There is much of picturesque charm for us, one hundred and eleven years later, to read parts of the "Introduction" to an edition published at New York in 1825 of "The Journal of Madam Knight." The journal is the good woman's diary of a trip she made on horseback from Boston to New York in 1704; and the author of the introduction contrasts *the mode of travel in 1825* with that of 1704. I quote:

"The reader will find frequent occasion to compare the state of things in the time of our author (1704) with that of the present period (1825), particularly with regard to . . . the facilities and accommodations prepared for travellers. Over that tract of country where she travelled about a fortnight, on horseback, under the direction of a hired guide, with frequent risks of life and limb, and sometimes without food or shelter for many miles, *we proceed* at our ease, without exposure and almost without fatigue, *in a day and a half*, through a well peopled land, supplied with good stage-coaches and public houses, *or the still greater luxuries of the elegant steam boats which daily traverse our waters.*"

The foregoing was written only four years before the "Stourbridge Lion" got under steam.

BEGINNINGS IN AMERICA.

America had been thinking of railroads long before the Rainhill Trials of 1829.

As early as 1812, the famous Colonel John Stevens of Hoboken wrote a pamphlet entitled: "Superior Advantages of Railways and Steam Carriages over Canal Navigation." In it he predicted that some day it would be possible for a steam carriage to move upon rails at a speed of 100 miles per hour. We do well to remember that there was not a mile of steam railway line in all America when Colonel Stevens made that prophetic statement.

In 1815, when the Napoleonic Wars were still raging, the legislature of the State of New Jersey passed an act creating a company to construct a railroad from the Delaware River near Trenton to the Raritan River near New Brunswick; but the enterprise came to nothing.

Again, as early as March 1820, the books for subscription to the stock of the Baltimore and Ohio Railroad were opened at Baltimore and closed within eleven days, when 22,000 stockholders had subscribed to over $4,000,000 of the capital stock of the company. But it was not until the 4th of July, 1828, that the construction of the railroad actually was started in a ceremony of breaking ground, participated in by Charles Carroll of Carrollton, the only then surviving signer of the Declaration of Independence. At that ceremony, Mr. Carroll said these words:

"I consider this among the most important acts of my life, second only to that of signing the Declaration of Independence, if even second to that."

We may look to the famous old "Stourbridge Lion" for record of the first beginnings of steam railway operation in America. I cannot do better than quote from the history of those beginnings in 1829, as recorded by my old friend, L. F. Loree, the American Founder of The Newcomen Society of England, whose description, written in 1922, I now quote to you:

"During the construction of the Delaware and Hudson Canal Company's railroad, John B. Jervis was chief engineer and Horatio Allen resident engineer, both later to hold very distinguished positions in railroad development. In 1827, Allen was sent to Europe in search of professional information on railroad matter. He was commissioned to take charge of the contract for the iron and to purchase three locomotives for the Delaware and Hudson Company, the first ever ordered and brought to this country. The order for the engines was placed with Foster, Rostrick and Company of Stourbridge, about 15 miles west of Birmingham. The first of the locomotives, the 'Stourbridge Lion,' was shipped from Liverpool on the sailing vessel 'John Jay' on April 8, 1829, arriving in New York about the middle of May. It was landed at the wharf of the West Point Foundry Company at the foot of Beach Street, now Pier 26, Hudson River, was blocked up in the yard, and steam put on. About the first of July, it was sent up the Hudson River to Rondout, transferred to a canal boat, arriving at Honesdale—the end of track—early in August. The Locomotive was set up by Horatio Allen, and alone he stood upon its platform on the first experimental trip, August 8, 1829. *His hand opened the throttle-valve upon the engine that turned the first driving wheel in America*, running up the track two or three miles and back, and repeating the performance several times, so that the 'Stourbridge Lion' was in operation in America *two months before* the 'Rocket' won in competition at Rainhill."

As Mr. Loree has shown us, the "Stourbridge Lion" was built in England.

EARLY AMERICAN LOCOMOTIVES.

The first locomotive *built in America* for actual service on a railroad was "The Best Friend of Charleston," constructed in New York City at this same West Point Foundry, for the South Carolina Railroad. Arriving at Charleston aboard the ship "Niagara" on October 23, 1830, the locomotive made its first excursion on January 15, 1831, the anniversary of the commencement of the railroad. Boiler explosion cut short its career after six months, because regrettably the negro fireman tired of the noise of steam blowing off, had tied down the safety valve.

It is generally conceded that the distinction of *second locomotive* built in America and long operated in actual service, goes to the famous "DeWitt Clinton," still preserved in replica by New York Central Lines. This engine made its historic trip on August 9, 1831, from Albany to the brow of the hill at Schenectady, when its train carried many distinguished personages. It made the run in less than an hour, at times reaching a speed of 30 miles per hour.

Steam railroad transportation in the United States was being established!

It is often difficult to set the actual "firsts" in history, and therefore mention should be made of early experimental locomotives, including Peter Cooper's "Tom Thumb" and Colonel Stevens' experimental locomotive at Hoboken.

It is my happy privilege, on this distinguished occasion here at Philadelphia, to pay tribute to the brilliant work of your fellow townsman, Matthias Baldwin, whose famous "Old Ironsides" made its first trial trip on November 23, 1832.

Railroading in America had started in earnest; and you may agree with me that it was significant that *before the year 1830 ended*, the legislatures of nearly every State in the Union had granted charters for railroads, and many of these roads were under construction.

A HAND-BILL OF 1832.

It is not to be supposed that always these plans for the building of railroads were without opposition:

There hangs today in my office a copy *of an early hand-bill* which I cherish. Its message is lurid if not persuasive;

vehement if not accurate. It breathes of outrages, monstrosities, casualties; in the best style of 1832.

A picture arrests our attention at the top of the hand-bill. The locomotive "Juggernaut" with its tender "Monopoly," pulling box cars marked "Camden & Amboy," belches forth black smoke as it proceeds (on the *wrong one* of the two tracks) up the erstwhile quiet Philadelphia street. Beneath its drivers a lovely young lady is being delicately ground into elemental atoms, while the cowcatcher gently upturns a two-wheeled carriage whose only occupant (in a high silk hat) is beginning to feel the force of gravity. The aforesaid lovely young lady's parents (Papa also in a high silk hat) appeal to the policeman on the corner, who with little emotion strokes full whiskers. The billboard on an adjacent theatre appropriately advertises: "The Road to Ruin." Nearby shops display significant "To Let" and "Removed" signs. It is not a cheerful picture.

Beneath, in a variety of type-faces that spoke eloquently of full fonts at the local printer's, we read breathless:

> "Mothers Look out for your Children:
> ARTISANS, MECHANICS, CITIZENS:
> when you leave your family in health, must you be hurried home to mourn a Dreadful Casualty: Philadelphians, your Rights are being invaded: Regardless of your interests, or the Lives of your Little Ones. The Camden and Amboy are laying a
> LOCOMOTIVE RAIL ROAD:
> Do you consent to be a
> SUBURB OF NEW YORK!!
> Rally People in the Majesty of your Strength and forbid
> THIS OUTRAGE!"

It would seem therefore that not always was railroad building without mild opposition, one hundred years ago.

CHARLES DICKENS: 1842.

As rail lines began to multiply and be extended through the country, we find amusing situations confronting the traveller: unavoidable changes, from railroad to railroad, and from train to ferry, and back again to train. For instance:

when *in 1842* Charles Dickens travelled from Boston to New York, he went from Boston to Worcester over one railroad, from Worcester to Springfield over another, by boat from Springfield to Hartford, by a third railroad from Hartford to New Haven, and there he went aboard a steamboat on Long Island Sound for the sail to New York City. When he left New York for Philadelphia he found it necessary to use two ferries and one railroad; the 90-mile trip consumed six hours. At the same date, the 13-hour journey from Philadelphia to Washington was made by a 3-hour boat ride, then 3 hours on a train, next a ferry boat, back again to a train, changing trains at Baltimore, and finally an arrival at Washington.

Four years later, in 1846, the Pennsylvania Railroad was formed, connecting together many small lines between Philadelphia and Pittsburgh.

Eleven years after Dickens' visit, that is in 1853, ten lines between Albany and Buffalo were consolidated into the New York Central Railroad.

The Pennsylvania System of today is the outgrowth of more than 700 corporations; and New York Central Lines of some 600.

MILESTONES.

The fortitude and endurance both of audience and speaker tonight would be exhausted were I to attempt to develop in detail the progress of railroading since the times of Charles Dickens. Let us not forget that, throughout, it is *Steam* that has upheld that progress.

Suffice it therefore to give you brief flashes of a very few of the *milestones:*

1844: Morse's telegraph and the first message between Baltimore and Washington. A new era opened for train dispatching.

1853: It now is possible to travel from New York to Chicago: with numerous changes of cars.

1855: First railroad bridge over Mississippi River, at Rock Island, Illinois.

1856: Bessemer and his process for making *Steel*—another new era.

1860: 30,600 miles of railway line in the United States, which leads the World.

1863: A block signal system.
1864: George Pullman's first new sleeping car: "The Pioneer," built for the Chicago & Alton.
1865: Steel rails.
1867: Pullman's dining car, the "Delmonico," also on the Chicago & Alton.
That year, too, an automatic *electric* block system, on the New Haven; and also the first mail car.
1868: Westinghouse and his air brake.
1869: May 10—at Promontory Point, Utah; the first transcontinental railway completed, when Union Pacific and Central Pacific joined tracks.
1872: A time table convention; out of which later grew Standard Time (in 1883).
First Circus Train: Mr. P. T. Barnum!
1873: The Panic of '73.
1877: Wooten's firebox—for anthracite.
1880: A refrigerator car appears.
The change-over to standard guage (4 ft. 8½ in.) is now being completed.
1881: Steam heat for passenger cars.
1887: Interstate Commerce Commission organized.
The M. C. B. automatic coupler.
First solid vestibule train.
1890: Compounding of steam locomotives.
1892: "Pennsylvania Limited" begins the era of de luxe travel.
1893: 20 hours, New York to Chicago, by "Exposition Flyer" via Lake Shore & Michigan Southern Railroad.
1895: Wide fireboxes, for soft coal.
1900: High boiler pressures.
1902: "20th Century Limited."
1904: All-steel cars—another new era.
L. F. Loree's first Mallet locomotive.
1906: Terminal electrification at New York City.
1909: Automatic Stokers.
1910: Superheaters.
1925: Diesel locomotives, for switching.
1932: Streamlining.
Today: Super-Speeds in railway service.

AMERICA'S RAILROADS IN 1936.

At a glance and to summarize: what has been the meaning of this progress which we have punctuated by a few milestones?

It has meant that in 1934 there were 423,000 miles of track in the United States; 48,000 locomotives; 44,000 passenger cars; 2,000,000 freight cars; and $25,800,000,000 invested, but capitalized at $18,800,000,000.

In normal times, the railroads employ 1,700,000 persons, to whom compensation of $2,800,000,000 yearly is paid; they spend $2,000,000,000 for supplies and pay $300,000,000 for taxes. They consume 25 per cent. of the coal produced in the country. 4,000 manufacturing companies in 38 States depend on railway purchases.

In a normal year, the railroads transport 30 million people 1,000 miles, and 440 million tons of freight 1,000 miles.

A GRAVE SITUATION.

An industry of such magnitude has problems, and each one of you knows how grave a situation confronts the carriers right now. *The Steam Locomotive*, long past the experimental stage, has a contribution of great importance to make towards a solution of these problems—a contribution in the direction of tremendous savings *yet to be secured* in operating expenses.

I wish to cite chapter and verse: the average yearly expense for maintenance of equipment for the ten-year period of 1919–1929, was $1,290,000,000, covering an average total tractive power in locomotives of 2,500,000,000 pounds. For the five years, 1930–1934 similar average yearly maintenance was only $738,000,000, or about *60 per cent.* of the former yearly figure; whereas the average tractive power for this latter period had decreased *only 4 per cent.*

The vital significance of these figures, for those familiar with railway operation, lies in two directions:

First, it is inescapable as to the extent to which maintenance has been deferred; and *Second*, and greatly more important, is the extraordinary degree of utilization possessed by the modern steam motive power which the railroads have.

THE MODERN STEAM LOCOMOTIVE.

It is important that you know something of the mechanical progress of the modern locomotive; something of what *Steam* is meaning to the railroads today; something that I best can interpret to you in that most readily understood of all common denominators; namely, dollars and cents:

From the actual operating records of the railroads, we learn that *the saving in fuel consumption* in freight service alone amounts to an amazing total of $478,000,000 since 1922. This has been accomplished by two means: *First*, a constantly and radically improved design of the modern locomotive; and *Second*, by improved operation in the utilization of motive power.

In just what proportion these savings are divided, it is impossible to state exactly; but when we compare the performance records of the steam locomotive of 1900 to 1910 with those of today; we find that *the amount of fuel used* per unit of work done *has been cut in half*. This tells its own story.

From another important engineering angle: we find that the average horsepower per driving axle, in the early 1900's, is about 400. Today, we are exceeding 1,200.

Moreover, it is during the past ten years, that the greatest rate of progress has been attained in this refinement of design.

Measured by drawbar pull at operating speeds, the modern steam locomotive outranks its average predecessor of a decade ago by an amount in excess of 55 per cent., *without one pound increase in weight on driving wheels, and with a far better effect upon track and bridges.*

Bear in mind that this accomplishment, of greatest utility value both to railroad management and to the cause of conservation of our natural resources, has been brought about without any widening of track gauge beyond that of the "De-Witt Clinton" and with practically no boring out of tunnels to increase the clearance diagram, and with the same width and height allowances that governed our ancestors.

Finally, do not forget that this 4,000 horsepower "mobile power plant," the Steam Locomotive, weighing up to 200 tons or more, *may be moving at speeds beyond 100 miles per hour;* and, for all of its locomotive wheels, has an actual physical contact on the rail, *of less than 10 square inches.*

This is not the whole story; because also the locomotive of today has:

(1) *Greater availability.* Instead of working 8 hours a day and 5,000 miles a month, we now have records of as much as 20,000 miles a month, in passenger service.
(2) *Tremendously lower maintenance* per unit of work.
(3) *Greater safety.*

I might cite, for our mutual satisfaction in this latter direction of safety, that in excess of 450,000,000 passengers were carried by Class 1 roads in 1935, nearly four times the population of the country. The records available covering twelve months of 1935 show that not one paying passenger was killed last year on Class 1 roads in the United States.

Despite public utterance by the long beards who point out to ignorant masses the inherent dangers of high centers of gravity, yet I tell you that it was *Steam* and the *Steam Locomotive* that carried safely the preponderance of this army of millions of travellers.

PROBLEMS.

Some have accused the railroads of being deaf to the cry of the new times, and deaf to the cry of vastly improved materials, methods, and development. I challenge such assertion, and I submit to you that years ago the railroads were fully cognizant of the advantages to be secured through use of special steels and improved design in freight car construction; and within the past few years they have at least indicated their willingness to welcome the advances in passenger car design and construction; including the streamlined train.

Do many of you have knowledge of the time, effort and money spent on research in connection with steel rails? Or in the art of welding? Or in safety appliances? Or in a hundred and one other directions?

As an industry, the railroads have been harassed. Not yet have they emerged from beneath that shadow. On one side, they are subject to rigid regulation at the hand of government, and on the other they are in competition with new agencies not so regulated or harassed.

Each hour of the Year 1934, the Class 1 roads paid out

$27,340 in taxes. Each hour they paid $173,000 to 1,000,000 workers. In other words, they paid for taxation about *one-sixth* of what they paid to 1,000,000 employees.

In justice to that manufacturing industry which I have the honor to represent on tonight's distinguished program, let me make one concession to the popular plea, and let me say in all sincerity it is my belief that the railroads can fairly be charged with deafness to the appeal of vast savings in railway operating expense, in that they have failed in large measure to avail themselves of the one tool that will appreciably reduce operating expenses, namely: *the Modern Steam Locomotive;* and at a time when rates on money were and are lower than in railroad history.

AND NOW I AM DONE.

And now I am done. James Watt and this international celebration have brought before us, in the present address, a variegated panorama. Together, we have taken a backward glance at Scotland and Watt, in 1736; we have inquired into the beginnings of Steam as applied to rail transportation; we have developed some few of the milestones of what is a great history; we have discussed the modern locomotive and its opportunity to aid in the solution of a present grave situation; and we have sought to paint with a broad brush the picture of *Steam and the Railroads.*

A discussion such as this, weaves both the past and the present into a common fabric. And in such direction, I cannot do better than quote, in conclusion, words taken from a recent brilliant lecture by my friend General James G. Harbord, addressing Princeton University under the Cyrus Fogg Brackett Lectureship. These were General Harbord's words, and you will see how appropriate they are. I quote:

"*The roads you travel so briskly lead out of dim antiquity, but you study the past chiefly because of its bearing on the living present and its promise for the future.*"

A TEST OF THE INTERVAL RULE IN THE $^2D_{3/2}$ STATE OF BISMUTH I.

BY

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ABSTRACT.

The hyperfine structure of the line λ 4722 of the arc spectrum of bismuth was investigated with a Fabry-Perot interferometer. After corrections were made for the mutual influence of the components, deviations from the Landé interval rule were observed in the $^2D_{3/2}$ state. These are accounted for by the addition of a $\cos^2$ term to the usual law of interaction.

INTRODUCTION.

The hyperfine structure of the line λ 4722.5 ($6p^3\ ^2D_{3/2} - 6p^2 7s\ (1)_{1/2}$) of the arc spectrum of bismuth (nuclear spin 9/2) [1] was recently investigated by Goudsmit and Back,[2] with a concave grating. They found that the Landé interval rule for the $^2D_{3/2}$ state was not exactly obeyed. However their measurements of the h.f.s. of this line were made with an instrument of relatively low dispersion, and complete resolution of the components was not obtained. They apparently made no corrections for the mutual influence of the components; consequently, these results are not conclusive as to the exact validity of the interval rule.

Because the validity of the interval rule is a point of great importance, it seemed desirable to investigate the question further. The $^2D_{3/2}$ state is of special interest for this purpose since the distances between h.f.s. levels are large enough to permit fairly good resolution of the components. Furthermore, the $6p^3\ ^2D_{5/2}$ state, the closest energy level which might exert a perturbing influence on $^2D_{3/2}$ is 4019 wave numbers away from it. The possibility of influence is further decreased by the fact that the j-values of the two states differ.

APPARATUS AND METHOD.

The entire optical system except the plate-holder was enclosed in a light proof beaver board box which had an

opening at one end to admit the radiation from the water cooled Schüler tube which was used as a source. The spectrograph included a collimator, a Fabry-Perot interferometer, a 60° glass prism, and a camera. The rigidity of the system was insured by mounting it on a lathe bed. All parts could be raised, lowered, and rotated with respect to each other. The reflecting power of the etalon was found to be 88 per cent. in the region investigated. Two spacers of thickness 2.90 and 3.14 mm. respectively were used.

Three different exposures of the fringe pattern were taken on each plate with the aid of ten wire screens, blackened chemically and of different transmissive power. Two sets of twenty second exposures for each screen were made between the three etalon patterns. In each set one exposure, representing 100 per cent. transmission, was taken without any screen present. In each set also, one exposure was repeated at the beginning and end of the series so as to give a check on accuracy. They were accurate to 1.5 per cent.

Microphotometer traces were made of the plates. From the trace of the calibration marks and the intensities mentioned above, a density-intensity curve was plotted. In order to locate the centers of the components and to determine the intervals between them, measurements of the distance of each point from the center of the pattern were made on several orders of each of the three Fabry-Perot patterns. The relative intensity for each reading was obtained from the density-intensity curve. The microphotometer traces indicated that complete resolution of the components was not obtained. It was then necessary to plot the pattern to a linear scale of dispersion and intensity in order to make it possible to apply corrections for the mutual influence of the components. Because of the wide variation of intensities of the components, it was not possible to plot all the components from the traces for one exposure. Therefore, a composite graph of the three exposures was made for each order, and the position of the center of each component was located. Since resolution was not complete, the positions of the centers found above were not the true ones. Therefore, a theoretical analysis had to be made in order to find their positions, had resolution been complete.

The broadening of the spectral lines under investigation is caused by the Doppler effect and the resolving power of the interferometer. (The line broadening due to collision damping was found to be negligible.) It was necessary to obtain an expression for the intensity at any point along the curve due to the combination of the two effects. Let $I(x)$ be the intensity at a point on the observed curve distant by an amount x from the true center. Then

$$I(x) = A' \int_{-\infty}^{+\infty} \frac{e^{-a\xi^2}}{1 + b \sin^2 \frac{\pi}{d}(x - \xi)} d\xi, \qquad (1)$$

where ξ is the distance from the true center of the line to a point on the Doppler curve. Expanding in series and integrating one obtains

$$I(x) = AI_0 \left\{ 1 - \delta^2 \frac{bI_0}{2} \cos \frac{2\pi x}{d} + \delta^2 \frac{(bI_0)^2}{2} \sin^2 \frac{2\pi x}{d} + \ldots \right\}, \qquad (2)$$

where $I_0 = \dfrac{1}{1 + b \sin^2 \dfrac{\pi x}{d}}$,

$$\delta = \frac{\pi}{d\sqrt{a}}$$

$b = \dfrac{4R}{(1 - R)^2}$ where R is the reflecting power of the interferometer.[3]

$a = \dfrac{4}{\Delta^2}$ where Δ is the width of the line at $1/e$ of the maximum intensity due to the Doppler broadening alone.

d is the linear distance between orders.

$A = A' \sqrt{\pi/a}$ and is the theoretical intensity of a component calculated from the intensity rules. Terms in δ^4 introduced a negligible change of 0.3 per cent. in the width of the curves at half maximum and were neglected.

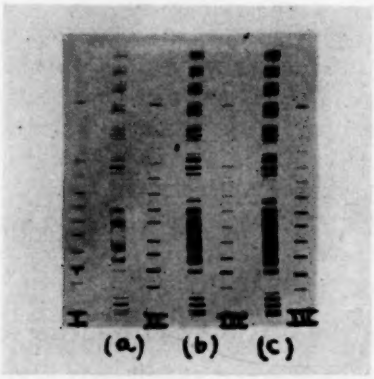
On the composite graph mentioned above, a set of theoretical curves (equation (2)) were drawn, one for each of the

six components. To each theoretical curve was added the background from the other five theoretical curves. The resulting curves had the same contour as the curves obtained from experimental data. The centers of these were plotted, and the shift of these centers from the centers of the theoretical curves was noted for each component. These shifts give a measure of the shift to the experimental center due to background. In other words, these shifts, when added in the proper direction to the centers of the curves, had the components been completely resolved, must give the positions of the experimental centers. Thus, from the experimental centers the true line of centers was deduced and used for the measurements of the intervals between components.

RESULTS AND INTERPRETATION.

Figure 1 is a photograph of one of the plates (No. 127) taken with a 2.90 mm. spacer. The Schüler tube was operated on an arc current of 0.28 amp. and a helium pressure

FIG. 1.

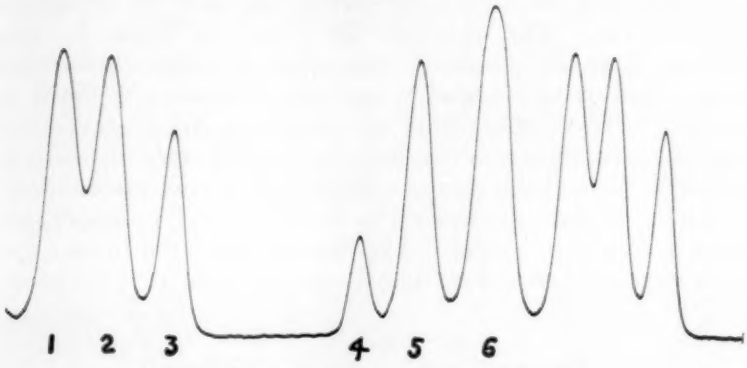


Photograph of h.f.s. of λ 4722.5 for three different exposures (*a*, *b*, *c*), and calibration marks (I, II, III, IV).

of 3 mm. of mercury. The pictures (*a*), (*b*) and (*c*) are exposures of the fringe pattern taken for 2, 4, and 6 minutes respectively, while Groups I, II, III and IV are density marks made with the aid of the blackened screens mentioned above. I and III correspond to 15 second exposures and II and IV to 20 second exposures.

Figure 2 is a microphotometer trace of the third order for exposure 127 (*b*). One observes that the components are not completely resolved.

FIG. 2.



Microphotometer trace of the third order for exposure *b*.

In Table I appear the value for the intervals obtained for four orders of the three exposures photographed on plate 127. The interval $\Delta\nu$ (5–4) for exposure (*a*) was not determined since component 4 in this exposure was too faint to be meas-

TABLE I.

Intervals between components ($\Delta\nu$ *in* 10^{-3} *cm.*$^{-1}$).
Plate 127. Spacer 2.90 mm.

	$\Delta\nu$ (2–1).	$\Delta\nu$ (3–2).	$\Delta\nu$ (4–3).	$\Delta\nu$ (5–4).	$\Delta\nu$ (6–5).
(*a*)	145.8	202.3			256.1
	147.4	200.9			257.1
	146.7	200.3			258.6
	145.7	203.3			258.1
(*b*)	147.1	202.0	625.9	197.0	257.8
	146.6	201.6	625.1	197.3	260.8
	145.9	203.0	624.8	194.4	257.9
	146.0	203.2		199.1	256.7
(*c*)	147.2	200.7	624.2	201.9	257.6
	147.8	199.6	624.3	198.1	259.1
	146.8	201.4	621.8	196.6	259.4
	146.2	201.2		197.8	259.7
Measured average.....	146.6	201.6	624.4	197.8	258.2
	±0.2	±0.3	±0.4	±0.6	±0.4
Corrected average.....	148.8	201.2		199.5	258.8

ured accurately (see Fig. 1). The average values for the intervals and their average deviations are listed. It was found that the uncertainty in the values for $\Delta\nu$ does not exceed 2×10^{-3} cm.$^{-1}$.

Corrections were made for mutual influence for two orders of plate 127. The averages are listed in Table I. One observes that the corrected values for the intervals between lines 2 and 3, and 4 and 5, are equal within the limits of accuracy. Since these intervals represent the energy difference between the same two h.f.s. levels, this fact can be considered to be a check on the validity of the corrections made.

Table II lists similar data for plate 163 photographed using a 3.14 mm. spacer. The intensities of the three exposures were relatively less than those for plate 127; therefore,

TABLE II.

Intervals between components ($\Delta\nu$ *in* 10^{-3} *cm.*$^{-1}$).

Plate 163. Spacer 3.14 mm.

	$\Delta\nu$ (2–1).	$\Delta\nu$ (3–2).	$\Delta\nu$ (4–3).	$\Delta\nu$ (5–4).	$\Delta\nu$ (6–5).
(*b*)	150.1	198.4			260.9
	149.2	201.9			260.5
	147.9	197.7			262.5
	147.5	198.2			263.9
(*c*)	150.4	199.4	622.1	200.4	261.1
	149.1	198.9	619.4	202.5	261.7
	149.6	196.5	623.1	203.9	261.0
	148.0	201.2		201.5	260.7
Measured average.....	149.0	199.0	621.5	202.1	261.6
	±0.3	±0.2	±0.8	±0.6	±0.3
Corrected average.....	149.9	200.4		201.2	260.0

the intensities for most of the components of 163 (*a*) were found to lie in the region below the linear portion of the intensity calibration curve and could not be used for measurements. Since complete resolution was not obtained, corrections for the mutual influence of the components were made; and the positions of their centers had resolution been complete, were determined. The values for these corrected intervals are also listed in Table II. The accuracy in measurement is of the same order of magnitude as for plate 127.

In Table III are listed additional data obtained from measurements made on plate 120 which was photographed using the 2.90 mm. spacer.

TABLE III.

Intervals between components ($\Delta\nu$ *in* 10^{-3} *cm.*$^{-1}$).
Plate 120. Spacer 2.90 mm.

	$\Delta\nu$ (2–1).	$\Delta\nu$ (3–2).	$\Delta\nu$ (4–3).	$\Delta\nu$ (5–4).	$\Delta\nu$ (6–5).
(*a*)	146.4	198.6			258.0
	145.9	199.2			260.0
	146.9	197.6			262.2
	145.1	197.8			261.7
(*b*)	145.6	202.1	624.8	195.2	255.1
	146.6	202.5	625.0	197.8	254.5
	146.9	204.5	623.0	195.9	257.2
	145.3	205.7		193.9	253.6
(*c*)	145.2	198.7	622.7	193.5	255.1
	145.8	200.8	627.7	194.3	254.2
	145.9	203.3	628.7	199.8	262.7
	146.3	202.5		201.6	262.0
Measured average.....	146.0 ±0.2	201.1 ±0.7	625.3 ±0.9	196.5 ±0.8	258.1 ±0.9

The values for the relative intensities of the components before and after corrections were made for mutual influence are given in Table IV. The theoretical values for the

TABLE IV.

Component.	Experimental Intensities.		Theoretical Intensities.		
	Uncorrected.	Corrected.	$i = 9/2$.	$i = 7/2$.	$i = 11/2$
1	60.1	54.2	53.8	45.5	60.0
2	57.0	51.2	50.8	47.7	52.9
3	37.2	33.5	33.8	34.1	33.7
4	21.2	18.2	18.5	15.9	20.4
5	54.6	50.8	50.8	47.7	52.9
6	103.8	101.6	100	100	100

intensities calculated from the intensity rules, assuming nuclear spins of 9/2, 7/2, and 11/2, are also listed. One observes that a value of 9/2 for the nuclear spin is in agreement with the value obtained by Goudsmit and Back from an investigation of the Zeeman effect.[1]

The results obtained from Tables I and II may be summarized as shown in Table V. Under *A* and *B* appear the values for the intervals obtained from plate 127 before and

TABLE V.

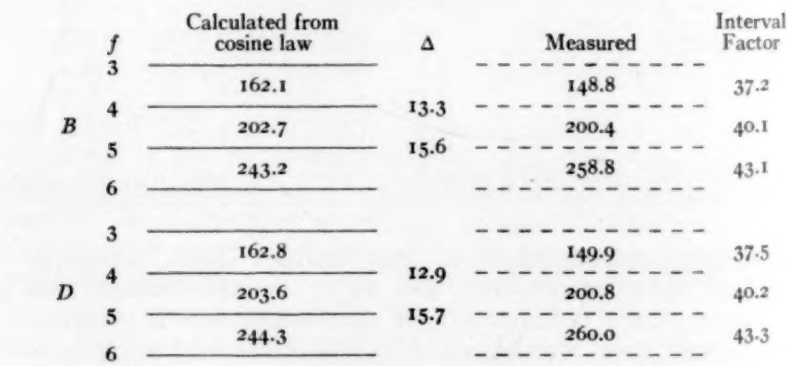
Intervals $\Delta\nu$ *in* 10^{-3} *cm.*$^{-1}$.

Δf.	2.90 mm. Spacer.		3.14 mm. Spacer.	
	A Uncorrected.	*B* Corrected.	*C* Uncorrected.	*D* Corrected.
f_{4-3}	146.4	148.8	149.0	149.9
f_{5-4}	199.7	200.4	200.6	200.8
f_{6-5}	258.2	258.8	261.6	260.0

after corrections were made for the influence of one component on the position of the other. *C* and *D* list the uncorrected and corrected intervals from plate 163. Δf represents the intervals between the h.f.s. energy levels of the $^2D_{3/2}$ state.

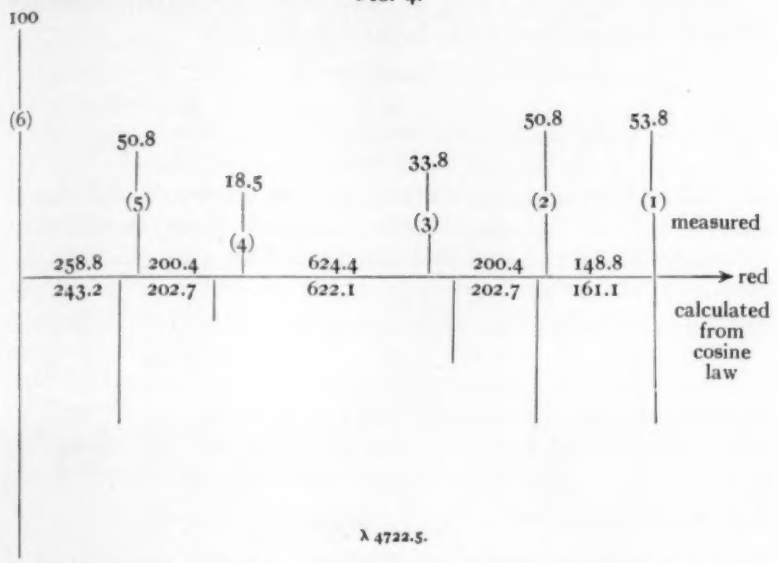
The broken lines in Fig. 3 show diagrammatically the relative positions of the h.f.s. levels obtained using the corrected values *B* and *D* listed in Table V. The interval factors to the right point to a definite deviation from the Landé interval rule. The position of the levels calculated from the simple cosine law using the observed values for the total splitting are represented to the left. One observes that

FIG. 3.



Splitting of $^2D_{3/2}$ state of Bi I.

FIG. 4.



Δ, the difference between the measured and calculated values, far exceed the limits of error.

It will be noted from Fig. 3 that the interval factors increase continuously with increasing f-values, thus indicating a shift of the components toward the longer wave-length region of the spectrum. Deviations having the same characteristic properties have been observed by Schüler and Schmidt [4, 5] in a number of levels in europium and lutecium. These shifts could not be accounted for on the basis of perturbations due to neighboring levels. Since they depend on the f-values of the h.f.s. levels, the authors assumed that the perturbations arose from a condition of asymmetry of the nucleus. The resulting shifts are accountable for by the addition of a $\cos^2(ij)$ term to the usual law of interaction. The energy of a h.f.s. level then, in such cases, becomes of the form

$$E = E_0 + a_1 \cos(ij) + a_2 \cos^2(ii). \qquad (3)$$

The values for the constants a_1 and a_2 were obtained using the total splitting and the largest interval, $\Delta\nu$ (6–5) since the latter required least correction for mutual influence.

These are listed in Table VI and were calculated from the corrected intervals B and D listed in Table V.

TABLE VI.

	a_1.	a_2.
B.....	276.7	12.6
D.....	277.9	12.8

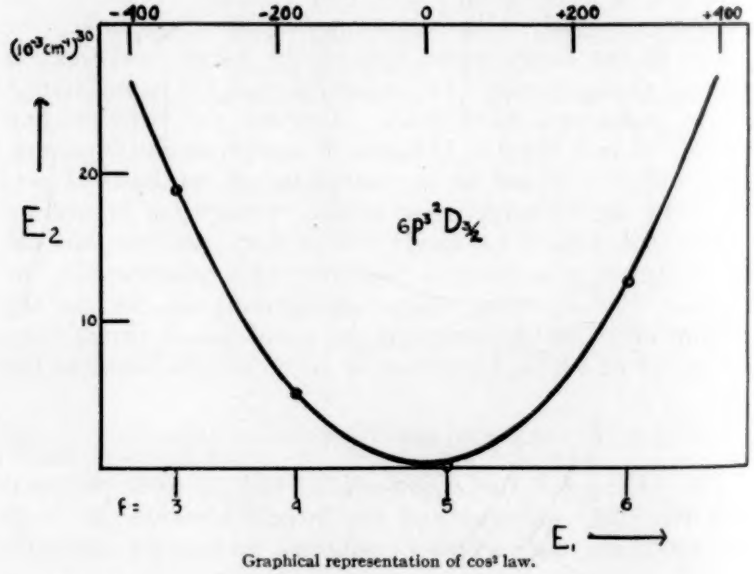
Table VII lists the values for the intervals calculated from equation (3) and those obtained from experiment. These results are shown graphically in Fig. 5 by plotting E_1,

TABLE VII.

Δf.	B.		D.	
	Calculated.	Measured.	Calculated.	Measured.
f_{4-3}.....	149.6	148.8	150.0	149.9
f_{5-4}.....	199.9	200.4	200.6	200.8
f_{6-5}.....	258.8	258.8	260.0	260.0

the unperturbed energy, as abscissa and E_2, the energy of perturbation, as ordinate. The resulting parabola shown in

FIG. 5.



Graphical representation of $\cos^3$ law.

figure 5 represents the calculated values for the perturbations. The four circles are the measured values of the four energy levels. One observes that the difference between the measured values and those calculated from the $\cos^2$ law lie within the limits of error.

It follows then, from this investigation, that the $^2D_{3/2}$ state of the arc spectrum of bismuth deviates from the interval rule, and that these deviations can be accounted for by the addition of a $\cos^2(ij)$ term to the energy.

While this paper was being completed for publication, an article by H. Schüler and Th. Schmidt [6] on the same subject appeared, and their results seem to be in agreement with those given in this paper.

The author wishes to express her appreciation to Professor G. Breit, who suggested the problem, for his valuable advice, and to Dr. R. Garman of the Washington Square College who kindly made the microphotometer records.

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Vierendeel Girder Bridge Introduced in America.—L. T. EVANS. (*Engineering News Record* Vol. 117, No. 14.) A contract was let recently for the first of eight structural steel Vierendeel girder bridges which will span one of the channels of the Los Angeles County flood control project. Riveted design was selected. This is believed to be the first bridge of this type to be employed in this country, although such rigid panel trusses without diagonal members have been used extensively in Europe and particularly in Belgium, the country of their origin. Since the Los Angeles bridge is to be built in a congested part of the city, many complications arose. The original channel was much narrower than the one selected for this improvement, so that the bridge span was increased from about 45 to 96 ft. Fixed channel and street grades limited the distance between road surface and the underline of the span to about 3 ft., thereby eliminating a deck structure. Visibility was essential as side streets intersected very close to the ends of the bridge. The city officials objected to any overhead bracing or to the use of a middle support. In addition to these requirements, it was desirable to use a vertical end post high enough to mark clearly the beginning of the bridge, thereby eliminating an arch or incline chord structure. After taking all of these factors into consideration, a Vierendeel girder was chosen.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

PENETRATION OF MOISTURE INTO MASONRY WALLS.

The tests of rates of penetration of water through masonry walls, described briefly in *Technical News Bulletin 226* (February 1936), are being continued. The walls are about 50 inches high and 40 inches long and 4, 8, or 12 inches in thickness. After aging and drying for from 1 to 3 months, they are being subjected to a test in which the water penetrates under the forces of capillarity and gravity only. Water is applied by means of a spray at the top of a wall, causing a continuous film of water on the exposed face of the wall. Observations of the performance of a wall include the time for dampness to penetrate the wall, the period for leakage (if any) to start, and the rate of leakage through the wall.

Following the completion of the capillary tests the walls are redried and then are tested under conditions resembling exposure to a strong wind and heavy rain. Water is again applied to one face near the top of a wall, in the same manner as in the capillarity test, producing a continuous film of water on the exposed surface. The effect of a strong wind is simulated by maintaining an air pressure of 10 lb./ft.^{2} on the exposed face of the wall. Some of the walls are being subjected to a third test in which water is applied by means of atomizers, while a difference in air pressure of 10 lb./ft.^{2} is maintained between the exposed and unexposed faces of the wall. In this test the rate of application of water is controlled to produce an effect similar to that of exposures to a rain of moderate intensity accompanied by a strong wind.

As expected, the rate of water penetration was increased by maintaining the air pressure on the exposed faces of the walls. The time for dampness to appear on the unexposed face was reduced, usually to less than one-half that required in the capillarity test. Similarly when leakage occurred, it

* Communicated by the Director.

started sooner and usually was in larger volume in the pressure test than in the capillarity test.

The performance of the walls was influenced by the quality of the workmanship, the thickness of the walls, the kind of brick, etc., but of these the quality of the workmanship was the most important factor. All of the walls of class B workmanship having open (unfilled) interior joints and flush-cut face joints leaked; whereas most of those with class A workmanship, having solidly filled interior joints and tooled face joints, showed little or no leakage. Of the walls built with a nearly impervious brick, none of those with class A workmanship leaked during the period of testing, which ranged from 1 to 14 days, but all of those with class B workmanship leaked, either through the facing or the backing, within 15 minutes after the start of the tests. The effect of differences in workmanship was somewhat less pronounced for the walls with more absorptive bricks, but the majority of those built with class A workmanship did not leak, whereas all with class B workmanship leaked in less than 1 hour. The quality of the workmanship had a similar effect upon the performance of the walls with structural tile backing and a facing of absorptive bricks.

For the walls of class A workmanship, those with the nearly impervious bricks gave the best performance. However, most of the data available to date are results of the first two tests in which water is applied at a rate greater than would normally result from exposure to natural rainfall. The walls of the more absorptive bricks have given relatively better performances in the third tests with the water being applied at a more normal rate. There was not an important difference in the performance of the walls built with the different kinds of brick and class B workmanship.

Each of the four cement-lime mortars used in the walls was satisfactory to the masons; all were considered to have satisfactory working properties. Although the rates of moisture penetration through the walls were, on the average, slightly less for walls with the cement-lime mortars rich in portland cement than for those rich in lime, the differences were too small to be significant.

INFLUENCE OF REPEATED FREEZING AND THAWING ON THE RELATION OF WATER ABSORBED TO PORE VOLUME OF BRICKS.

In connection with freezing and thawing tests of bricks, the so-called "C/B" [1] ratio has been proposed (with limitations for compressive strength and absorption) as a factor for predicting whether a specimen will remain sound or fail when subjected to a certain number of cycles of freezing and thawing. In the C/B ratio "C" represents the weight of water absorbed by the specimen by immersion for 48 hours at room temperature, and "B" the total weight of water absorbed by the 48 hours immersion followed by 5 hours boiling. The specimen is cooled while immersed to room temperature before weighing.

Saturation of the specimen by water immersion followed by boiling and cooling has been in use for a number of years as a means of determining the pore volume of specimens. The C/B ratio was apparently devised as a means of expressing the relation between the equivalent of pore volume occupied by water and the total pore volume of the specimen.

It seems practically impossible to completely fill all the open or "active" pores of the specimen by saturation. Pore volumes as determined by the saturation method have been found to be in error from a fraction of one per cent. to more than two per cent. when compared to porosity values determined by the "air expansion" method, capable of measurements to a high degree of accuracy.

Although the C/B ratio appears satisfactory for the purpose for which it was developed, it is not suitable for application to problems of a fundamental or research nature. To supply the need for such purposes, the ratio $W/V = R$ has been proposed in which "W" = per cent. volume of pores occupied by water after immersion at 24° C. ± 2° for 48 hours, "V" = per cent. pore volume of the specimen determined by the air expansion method, and "R" = the ratio expressed decimally.

In a study of pore structure and its relation to the resistance of structural clay products to disintegration by weathering agencies, freezing and thawing tests are in progress

[1] A.S.T.M. Reprint 1935, "Report of Committees C–3 on Brick."

on a number of soft mud "salmon" bricks and stiff mud side-cut shale bricks. At the present time 24 freezing and thawing cycles have been completed.

The bricks are immersed in water for 48 hours, the per cent. volume of water absorbed determined, and the bricks are placed on edge in 1/4 inch of water and frozen. After freezing, the bricks are thawed in "tap water" and the per cent. volume of water absorbed again determined for each cycle of freezing and thawing.

The results indicate that the per cent. volume of water absorbed has increased in one case as much as 3.81 during the 24 cycles of freezing and thawing, and therefore the "*R*" value has also increased, in the maximum case 22 per cent. This indicates that there is less pore space for relief of the expansion caused by ice formation for each consecutive freezing.

In general, the volume per cent. water contained by the specimens at the end of each freezing and thawing when plotted against the sequence number of the cycle, indicates that the absorption increases asymptotically toward a constant value near the per cent. porosity value "*V*."

METHODS OF TESTING PLASTICS.

The haziness and scratch resistance of transparent plastics are of prime importance in connection with their use as windshields on aircraft. In a study of these materials now under way at the Bureau in coöperation with the National Advisory Committee for Aeronautics, special methods have been developed for the measurement of these properties. These were described in a paper by G. M. Kline and B. M. Axilrod, presented as part of a symposium on synthetic resins and plastics at the Pittsburgh meeting of the American Chemical Society on September 10, 1936.

The clarity of plastics is generally considered as dependent upon two factors, light transmission and light scattering by particles or by surface imperfections. The military services specify that the plastic sheet shall transmit at least 68 per cent. of white light when tested within 30 days of the date of manufacture. However, the transparent organic plastics

now in use transmit more than 85 per cent. of the incident light and some are equal to glass in this respect. Haze or fog, produced by the scattering of the light on dust particles, undigested fiber, or the like in the plastic, is of equal importance with the light transmission of the plastic in relation to its visual clarity. Because of the difficulty of applying previous methods for the determination of haziness, government specifications have not included quantitative limits for it in plastics. The instrument developed in the present investigation permits a rapid and reliable measure of this property as well as of light transmission.

The apparatus consists essentially of a photoelectric cell, a light source, a 6-volt storage battery and a microammeter. The percentage of light transmission of the plastic is measured with the sample covering the aperture of the photocell, which is inclosed in a blackened box. The sample is then placed over an aperture at the light source, 18 inches distant from the photocell. The difference between the two readings is a measure of the light scattered by particles and surface imperfections; haziness is defined as the percentage of the total light transmitted at the photocell which is scattered when the sample is placed over the aperture at the light source. It was found that the relative order of clarity of the plastics as determined by visual inspection by several individuals was essentially the same as indicated by values for haziness obtained with this instrument.

The comparative ease with which transparent organic plastics are scratched is a major obstacle to their substitution for glass in many applications where their toughness and non-splintering characteristics would be advantageous. However, the plastics vary considerably among themselves in scratch resistance and it is desirable to have a method of measuring this property. A sklerometer used in testing metals, namely the Bierbaum "Microcharacter," was found to be suitable for use with plastics. The diamond tool which is in the form of a cube yields scratches which are geometrically similar regardless of the load. The scratch resistance numbers calculated as the quotient of the load in kilograms divided by the square of the scratch width in millimeters are, therefore, independent of the load. The acrylate resins,

which are now finding extensive use on airplanes and lighter-than-air craft, notably, the "Hindenburg" because of their lightweight and flexibility, were found to be the most resistant to scratching of the materials studied.

The indentation hardnesses of the plastics were determined with a Vickers hardness testing machine, using a load of 5 kilograms and an applied load time of 10 seconds. Styrene resin was the most resistant to indentation; the cellulose plastics were in all cases indented more readily than the resins. Comparison of the scratch resistances with the indentation values indicated that while very good correlation is evident for some materials, in other cases the two coefficients are not similar, notably for styrene, vinyl and cellulose acetate plastics.

A survey of the data in the literature on the properties of synthetic and natural resinous compositions, cellulose derivatives, and protein plastics indicates that it is very difficult to correlate the published values for the different materials because of non-uniformity in the methods of testing. The plastics industry is aware of this condition and a number of firms have indicated their desire to coöperate in an investigation of test methods for plastics, undertaken in collaboration with the manufacturers' laboratories for the purpose of establishing standard specimens and test procedures.

PRESSBOARD FROM CORNSTALKS.

A hard, dense board, resembling grainless wood has been made from cornstalks in the Bureau's laboratories. A mechanical treatment was necessary to reduce the cornstalks to fiber bundles of the most suitable length and to soften them to some extent. This procedure was best accomplished by a two-stage treatment in separate machines. After the stalks were reduced to suitable fiber bundles in a water suspension, they were run onto a forming machine and made into wet mats. These were cold pressed to remove some of the excess water and then dried under heat and pressure. The optimum conditions for drying seemed to be 150° C. and 400 to 500 lb./in.^{2}. The degree of dryness at which the boards should be removed from the hot press was most satisfactorily determined by electrical resistance measurements.

Different types of boards were produced by varying the degree of cooking given the raw material. Stalks digested with water under pressure, followed by the necessary mechanical treatment to reduce them to fiber bundles, produced boards of a density of about 1.0 and a modulus of rupture of 5,000 to 8,000 lb./in.^{2}. By treating cornstalks by mechanical means alone, boards having a density of around 0.7 and a modulus of rupture of 2,500 to 4,000 lb./in.^{2} were produced.

The resistance of the boards to the absorption of water was increased by precipitating a rosin or paraffin size on the surface of the fiber bundles preceding the wet mat formation.

The cost of producing these boards was estimated to be $16 to $18 per 1,000 board feet of 1/8 in. board.

The complete account of this work will be found in Miscellaneous Publication M123, copies of which are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

PAPER PULP FROM CEREAL STRAWS.

Miscellaneous Publication M124, which has just been released, describes the production at the Bureau of pulps suitable for book and writing paper from cereal straws by a modified sulfate process. In this process the strength of the purified fibers was preserved by using less drastic treatments than those usually given wood.

The pulping process involved the removal of the incrusting materials with chemicals, mechanical separation and softening of the fibers, separation of large fiber bundles and undissolved impurities from the pulp, and bleaching. The incrustants were dissolved by steeping the straw in water for 1 hour at 100° C. and then cooking it for 3 hours at 147° C. with a solution containing 1 to 2 per cent. of sodium sulfide and 8 to 9 per cent. of caustic soda based on the weight of the straw. After washing the cooked material, it was beaten for 90 minutes, treated with a 3-stage bleaching process, screened, and centrifined.

The test sheets prepared from the pulps indicated that oat straw produced paper of the greatest strength, but was the most difficult to bleach; rye straw produced the most

brittle paper, but was the easiest to bleach; and wheat straw was intermediate between the two. The yields, calculated from test sheet data, were from 38 to 43 per cent. of bleached pulp from the bone-dry raw material.

Cost data were not estimated, but a comparison of the time of cooking, yields, and chemical consumption with commercial wood processes indicated that the time and chemicals for cooking were slightly less, the yields the same or slightly less, and the bleach consumption greater for straws.

Copies of this publication are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

AIR CONDITIONING REQUIREMENTS OF MULTICOLOR OFFSET PRINTING.

As pointed out in previous numbers of this Bulletin, the multicolor offset process of printing requires special adjustment of the moisture content of the paper, in addition to constant atmospheric conditions during printing, for best results. The procedure recommended by the Bureau (*J. Research N.B.S.*, **16**, 93; February, 1936; RP. 859), based on results of printing tests, requires conditioning the paper at one relative humidity and printing at another. For best results, the paper should be prepared for printing by adjusting the moisture content to about 0.5 per cent. above equilibrium with the pressroom air, and printed under constant temperature and humidity in the pressroom. The air conditioning requirements for quality multicolor printing by the modern high-speed offset process are outlined in an article by C. G. Weber which will appear in a future number of *Refrigerating Engineering*.

THE UNDERLYING PRINCIPLES OF THE SYSTEM OF ELECTRICAL UNITS.

The electrical units, ohm, ampere, volt, coulomb, farad, and henry, are daily employed by many thousands of people who do not understand the principles which have been used to establish these units. Such an understanding may be of little importance when one is concerned with a single unit which can

be referred to a standard that is furnished by some standardizing laboratory. However, occasions frequently arise where the relationships between the units in the electrical system, and those in the mechanical system are required. For example, it often becomes necessary to compute the force which is exerted between two bus-bars that carry heavy currents. If these bus-bars are not sufficiently well fastened to their insulating support, the electromagnetic forces with high currents may become great enough to loosen them. The computation of the force between conductors can readily be accomplished when the basis of the electromagnetic system is understood. The underlying principles by which the system of units is established are made clear in a paper by Dr. H. L. Curtis, which will appear in an early number of the *American Physics Teacher*.

COMPARISON OF RADIO-FREQUENCY STANDARDS.

A method of precisely measuring the frequency difference between two standards which have nominally the same fundamental frequency is being applied at the Bureau to the continuous intercomparison of the piezo oscillators in the national primary standard of frequency.

The customary method of measuring the frequency difference between two piezo oscillators utilizes the beat frequency between the two standards at the fundamental frequency or one of the harmonics. The new method, which is described in the *Journal of Research* for October (RP. 925), utilizes the frequency produced by heterodyning two consecutive harmonics to obtain any desired precision of comparison without necessitating the operation of any circuits at exceedingly high frequencies.

Liquefied Gas Used as a Motor Fuel.—W. T. ZIEGENHAIN. (*Oil and Gas Journal*, Vol. 35, No. 18.) Without replacing or interfering with the normal operation of the regular gasoline carburetor on his car, Murray D. Etherton, an engineer located at Seminole, Okla., has equipped his 1936 car to run either on liquefied gas or gasoline, the switching from one fuel to the other simply involving the turning of two valves. The liquefied gas is a by-product of a local natural gasoline plant and has an initial boiling point of about 12° F. It is a mixture of propane, butane, and iso-butane and as such has little commercial value. The only equipment needed is a small 20 gallon tank located in the rear of the car into which the fuel enters under pressure, a small pressure regulator, a heating coil, and a commercially-built and assembled Ensign gas pressure regulator, jet and mixing throat. The throat is attached to the regular carburetor in place of the air filter and the air filter is attached to the inlet end of Ensign throat. In the operation of the car, when using this type of fuel there is no chance for vapor locking due to the nature of the carburetor system. The car is easier to start and because of the naturally high octane value of the liquefied gas fuel no knocking occurs in the engine. Mr. Etherton has operated his car on this fuel for about 2 months and now plans to utilize the refrigerating value of the fuel to help cool the air inside his car.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, OCTOBER 21, 1936.

The regular monthly meeting of The Franklin Institute was called to order at 8:30 o'clock by the President, Mr. Nathan Hayward, who immediately called upon the Secretary for the business of the evening.

The Secretary announced that the minutes of the previous meeting had been printed in the JOURNAL and unless there were objections or corrections, they would stand approved. As there were no objections, the President declared that the minutes were approved. The Secretary also reported that 355 members had been added to the roll since the last meeting. He called attention to the Traveling Chemistry show, which has recently been made into a portable demonstration and is now being shown to schools, colleges and societies away from Philadelphia.

Mention was also made of the resumption of the lectures on music, on alternate Sunday afternoons, by Mr. Guy Marriner, Associate Director in Charge.

He then introduced Dr. Samuel W. Fernberger of the University of Pennsylvania, who presented to the Institute for its museum, on behalf of Dr. Thomas S. Gates, President, and the Trustees of the University of Pennsylvania, a specimen of dried plant from the herbarium of Gregor Johann Mendel, Abbott of the Augustinian Monastery of St. Thomas at Brünn, Germany. The President accepted the gift and requested that the thanks of the Institute be conveyed to the donors.

Dr. Fernberger was then invited to address the meeting on the subject which had been scheduled: "Mendel and his Place in the Development of Genetics."

The speaker pointed out the importance of genetics as a science for all the biological sciences and arts, including medicine. After describing the development of the genetic theory up to the time of Mendel's experiments, an attempt was made to evaluate his contribution. Some indication was given to the development of the science during the past thirty-five years. This was followed by an interesting account of Mendel's life, with special emphasis on his experimental period and the fate of the reports of his experiments. The subject was illustrated by diagrams.

Mr. Wetherill was recognized and expressed the thanks of the meeting to the speaker. Adjourned.

HENRY BUTLER ALLEN,
Secretary.

RESOLUTIONS ADOPTED BY THE BOARD OF MANAGERS ON THE OCCASION OF THE DEATH OF MR. WILFRED W. FRY.

In the death of Wilfred W. Fry, The Franklin Institute has lost a member who, visualizing the activities of the Institute with the highest idealism but tempering his conclusions with sound wisdom, was one of the few to understand the possibilities of the museum in the early stages of planning.

Mr. Fry was elected to the Board of Managers in 1933 and served continuously since that time. He not only took great interest in all the activities but gave freely of his professional advice and analysis to the problems in that field in which he was preëminent.

It will be hard indeed to carry on without that friendly encouragement and sound advice which he gave so generously; therefore, with a deep sense of personal loss, be it

Resolved: That the Board of Managers of The Franklin Institute record with profound sorrow the death on July 27, 1936, of its esteemed and distinguished member, Wilfred W. Fry, and be it

Resolved further: That the sympathy of the Board be extended to Mrs. Fry in her great bereavement; and be it

Resolved further: That a copy of the above preambles and resolutions be sent to Mrs. Fry and a copy be published in the JOURNAL OF THE FRANKLIN INSTITUTE.

September 16, 1936.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, October 14, 1936.)

HALL OF THE COMMITTEE,
PHILADELPHIA, OCTOBER 14, 1936.

MR. JOHN A. VOGLESON *in the Chair.*

The following report was presented for final action:
No. 2988: Automatic Air Control.

The following reports were presented for first reading:
No. 3007: Radiographic Testing by Gamma Rays.
No. 3014: Discovery of the Positron.

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

RECENT ADDITIONS.

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BOOK REVIEWS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 558, Turbulence Factors of N. A. C. A. Wind Tunnels as Determined by Sphere Tests, by Robert C. Platt. 21 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

Results of drag and pressure tests of spheres having diameters of 2, 4, 6, 8, 10, and 12 inches in eight N. A. C. A. wind tunnels, in the air ahead of the carriage in the N. A. C. A. tank, and beneath an autogiro in flight are presented in this report. Two methods of testing were employed, one involving measurements of sphere

drag and the other measurements of the pressure difference between the front stagnation point and the rear portion of the sphere. Satisfactory correlation between the two methods was obtained experimentally, as set forth in an appendix to the report.

The following table indicates the relative status of the wind tunnels tested as regards the amount of turbulence normally encountered in their air streams, the least turbulent being listed first:

Full-scale tunnel.
24-inch high-speed tunnel.
20-foot tunnel.
Model of the full-scale tunnel.
7- by 10-foot tunnel.
5-foot vertical tunnel.
Free-spinning tunnel.
Variable-density tunnel.

A "turbulence factor" for each wind tunnel, defined as the ratio of the critical Reynolds Number of a sphere in a nonturbulent air stream to the critical Reynolds Number in the tunnel, was obtained from sphere-test results. When the Reynolds Number of a model tested in a wind tunnel is multiplied by the turbulence factor for that tunnel, the resulting value is an "effective" Reynolds Number; that is, the Reynolds Number at which certain critical flow conditions obtained in the actual test would be approximately reproduced in a nonturbulent stream. When this method is used to obtain the scale-effect variation of maximum lift coefficient and drag coefficient at zero lift of certain well-known airfoils, data obtained in various wind tunnels under a wide variety of turbulent conditions are brought into satisfactory agreement.

Report No. 559, The Forces and Moments Acting on Parts of the XN2Y-1 Airplane During Spins, by N. F. Scudder, 8 pages, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price five cents.

The magnitudes of the yawing moments produced by various parts of an airplane during spins have previously been found to be of major importance in determining the nature of the spin. Discrepancies in resultant yawing moments determined from model and full-scale tests, however, have indicated the probable importance of scale effect on the model. In order to obtain data for a more detailed comparison between full-scale and model results than has hitherto been possible, flight tests were made to determine the yawing moments contributed by various parts of an airplane in spins. The inertia moment was determined by the usual measurement of the spinning motion, and the aerodynamic yawing moments on the fuselage, fin, and rudder were determined by pressure-distribution measurements over these parts of the airplane. The wing yawing moment was determined by taking the difference between the gyroscopic moment and the fuselage, fin, and rudder moments.

The numerical values of the wing yawing moments were found to be of the same order of magnitude as those measured in wind tunnels. A direct comparison between wind-tunnel and flight results will be possible as soon as the tests of a model of this airplane have been completed on the N. A. C. A. spinning balance.

The pressure-distribution tests incidentally demonstrated the favorable interference produced by the horizontal tail surfaces on the part of the vertical surfaces below them and the unfavorable interference produced on the part above them.

Report No. 566, Ground-Handling Forces on a 1/40-Scale Model of the U. S. Airship "Akron," by Abe Silverstein and B. G. Gulick. 14 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

An investigation was conducted in the N. A. C. A. full-scale wind tunnel to determine the ground-handling forces on a 1/40-scale model of the U. S. airship "Akron." Ground-handling conditions were simulated by establishing a velocity gradient above a special ground board in the tunnel comparable with that encountered over a landing field. The tests were conducted at Reynolds Numbers ranging from 5,000,000 to 19,000,000 at each of six angles of yaw between 0° and 180° and at four heights of the model above the ground board.

The ground-handling forces vary greatly with the angle of yaw and reach large values at appreciable angles of yaw. Small changes in height, pitch, or roll did not critically affect the forces on the model. In the range of Reynolds Numbers tested, no significant variation of the forces with the scale was disclosed.

Report No. 563, Calculated and Measured Pressure Distributions Over the Midspan Section of the N. A. C. A. 4412 Airfoil, by Robert M. Pinkerton. 16 pages, illustrations, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

Pressures were simultaneously measured in the variable-density tunnel at 54 orifices distributed over the midspan section of a 5- by 30-inch rectangular model of the N. A. C. A. 4412 airfoil at 17 angles of attack ranging from −20° to 30° at a Reynolds Number of approximately 3,000,000. Accurate data were thus obtained for studying the deviations of the results of potential-flow theory from measured results. The results of the analysis and a discussion of the experimental technique are presented.

It is shown that theoretical calculations made either at the effective angle of attack or at a given actual lift do not accurately describe the observed pressure distribution over an airfoil section. There is therefore developed a modified theoretical calculation that agrees reasonably well with the measured results of the tests of the N. A. C. A. 4412 section and that consists of making the calculations and evaluating the circulation by means of the experimentally obtained lift at the effective angle of attack; i.e., the angle that the chord of the model makes with the direction of the flow in the region of the section under consideration. In the course of the computations the shape parameter ϵ is modified, thus leading to a modified or an effective profile shape that differs slightly from the specified shape.

R.

HANDBOOK OF ENGINEERING FUNDAMENTALS, prepared by a staff of specialists under the editorship of Ovid W. Eshbach. Unpaged, tables, 14 × 22 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $5.00.

Advances in technology have now reached a stage that the familiar handbooks of the various basic engineering sciences need amplification and enlargement. To do this to the extent necessary would increase the size of the handbooks to unwieldy proportions. This was quickly realized by the publishers of the book at hand, who are endeavoring to overcome the difficulty by a new arrangement—the avoidance of duplicate material in handbooks devoted to such subjects as mechanical and electrical engineering. The duplicate material includes the fundamentals of all engineering, the laws and theories of science basic to engineering practice, and this material is published in this separate book as volume one of a series of handbooks. Not only does the elimination of this duplicate material from the usual form of handbook provide means for the enhancement of the value of the handbooks which are to follow, but it also allows a more thorough and clear presentation of engineering fundamentals.

This book, volume one, bears out the value of the new approach to the handbook problem. It is essentially a summary of the principles of mathematics, physics, and chemistry, the properties and uses of engineering materials, the mechanics of solids and fluids, and the commonly used mathematical and physical tables, to which has been added a discussion of contractural relations. The latter discussion as well as certain other interesting features of the book as, for instance, the part devoted to the mathematics of finance including interest and discount, annuities and sinking funds, should place it in great demand.

Attention should also be directed to the new format, an abandonment of the small size page and type and substituting a 5½ by 8⅜ inch page permitting a larger and more legible type, larger illustrations and diagrams.

The editor is well fitted by training and experience for the direction of the preparation of such a book. The work reveals a keen insight into the educational and technical requirements of industry and of engineering curricula. It therefore covers the needs of all from students to the experienced engineers.

R. H. OPPERMANN.

THE MICROSCOPE, by Simon Henry Gage, sixteenth edition. 615 pages, illustrations, 15 × 23.5 cms. Ithaca, Comstock Publishing Company, Inc., 1936. Price $4.00.

For a book to reach its sixteenth edition is an unusual occurrence. It denotes popularity as well as progress of the subject treated. In the case of the book at hand, the reason for its popularity is very apparent almost at first glance, and its contents alone indicate the rapid progress of the subject.

The purpose of the book is to give the guidance by which those unfamiliar with the microscope and the methods of work with it can gain an intelligent understanding of the instrument, its limitations, and its possibilities for aiding one to arrive at truth. It has also the added purpose of bringing together the scattered information concerning new apparatus and methods so that older workers may make use of them with a minimum amount of time and effort.

The subject is covered in remarkable completeness and clarity. Microscopes in general and their parts are described, then detailed chapters are devoted to bright field and dark field microscopy, the polarizing microscope, the micro-spectroscope, and the ultra-violet microscope. The need of careful observation and the interpretation of appearances is discussed together with drawings and photographs, also the preparation and preservation of specimens. One feature of this edition is the additional chapter on micro-incineration which gives the method by which the fixed mineral salts in the cells of the soft tissues may be shown in position. The last chapter gives a brief history of lenses and microscopes.

The author is a very careful writer, choosing the method of presentation with much forethought. Drawings and illustrations are plentiful throughout the book. A bibliography arranged by authors is appended and suggestions of sources of new information are given.

Too much emphasis cannot be laid on the efforts of the author to present his subject clearly and to give every assistance to the student. When detailed explanations are required they are made and, as at the end of each chapter, when further reading or perusal is of value, such is directed. All of these and more, when combined, as is here the case, make up an outstanding book, valuable as a text, a practical guide, and a reference work.

R. H. OPPERMANN.

PRINCIPLES OF HEATING, VENTILATING AND AIR CONDITIONING, by Arthur M. GREENE, Jr., Dean and Professor of Mechanical Engineering, Princeton University. 446 pages, tables illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc. London, Chapman & Hall, Ltd., 1936. Price $4.50.

Again the progress of science in direct application to human comfort has reached a point where it is necessary to enlarge and amplify topics, the principles of which were well grounded, and to make additions in the form of new topics. Heating and ventilating engineering has made steady progress to more efficient and economical equipment for many years, in fact a comparison of present day methods and results with what was in existence twenty years ago will reveal great strides. But there is a new industry on the horizon which, it has been said, will be one of the greatest. This is air conditioning. Because it is so closely related to heating and ventilating, one cannot be thoroughly understood without knowledge of the other. In this book they are interwoven.

The book is intended for those who have a basic knowledge of thermodynamics and those having this will have no difficulty in following through its order of treatment. It begins with a treatment on methods of application of the principles of heating, ventilating and air conditioning, then proceeds through chapters devoted to properties and conditioning of air, heat transmission through walls, radiation, the calculation of heat requirements, steam and hot water heating, unit heaters, warm air and district heating, controls, etc. Throughout the book reference is made and detailed explanations given to various makes and types of equipment for heating and ventilating. Refrigerating apparatus is also included to a certain extent, covering vacuum and compression systems.

As to its completeness of treatment, the author states in the Preface, "Although the author has endeavored to bring all data needed for design into one volume to serve as a handbook for the engineer and architect, the work has been written as a textbook. . .." The style of presentation is interesting and impressive. At the end of each chapter, problems are given for exercise and the results are given in the back of the book. An appendix contains a large amount of valuable data in the form of tables. A subject index completes the book.

This book can be recommended as a modern text and reference book to all those who may have occasion for activity in this field.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Electrical Engineering in Radiology, a Treatise on the Nature and Function of Electrical Equipment for X-Ray Work in Medicine and Industry, by L. G. H. Sarsfield. 284 pages, plates, tables, 14 × 22 cms. Pittsburgh, Instruments Publishing Company, 1936. Price $6.00.

Principles of Heating, Ventilating and Air Conditioning, by Arthur M. Greene, Jr. 446 pages, illustrations, tables, 15 × 23.5 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $4.50.

Why Quit Our Own, by George N. Peek and Samuel Crowther, 353 pages, 14 × 22 cms. New York, D. Van Nostrand Company, Inc., 1936. Price fifty cents.

An Advanced Course in General College Physics, by Paul Leverne Bayley and Charles Clarence Bidwell. 340 pages, tables, illustrations, 14.5 × 22.5 cms. New York, The Macmillan Company, 1936. Price $3.50.

The Microscope, by Simon Henry Gage, 16th edition. 617 pages, tables, illustrations, 15 × 23.5 cms. Ithaca, Comstock Publishing Company, Inc., 1936. Price $4.00.

Handbook of Engineering Fundamentals, prepared by a Staff of Specialists under the Editorship of Ovid W. Eshbach. Unpaged, tables, 14.5 × 22 cms. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $5.00.

Chemical Engineering Catalog, 1936, Twenty-first Annual Edition, The Process Industries Catalog, collected, condensed and standardized data on Equipment, Machinery, Laboratory Supplies, etc. 913 pages, 21 × 28.5 cms. New York, Reinhold Publishing Corporation, 1936.

National Research Council, Transactions of the American Geophysical Union, Seventeenth Annual Meeting, April 30, May 1, 2, 1936, Washington, D. C., Parts I and II. 17.5 × 25.5 cms. Washington, Council, 1936.

United States Coast and Geodetic Survey, Special Publication No. 207, Geodetic Operations in the United States, 1933–1935, by William Bowie. 25 pages, tables, 25 × 30 cms. Washington, Government Printing Office, 1936.

Canada, Dominion Bureau of Statistics, Report on the Mineral Production of Canada during the Six Months Ending June 1936. 32 pages, 21.5 × 28 cms. Ottawa, King's Printer, 1936.

Bell Telephone Laboratories, Monographs: B–931, A New High-Efficiency Power Amplifier for Modulated Waves, by W. H. Doherty, 22 pages, illustrations. B–937, Relation of Penetration and Decay in Creosoted Southern Pine Poles, by R. H. Colley and C. H. Amadon, 17 pages, tables. B–938, The Shunt-Excited Antenna, by J. F. Morrison and P. H. Smith, 24 pages, illustrations. B–944, Dial Switching of Connecticut Toll Calls, by W. F. Robb, A. M. Millard and G. M. McPhee, 25 pages illustrations. 4 pamphlets, 15.5 × 23 cms. New York, Bell Laboratories, 1936.

National Advisory Committee for Aeronautics, Technical Notes No. 579, Charts for Calculating the Performance of Airplanes Having Constant-Speed Propellers, by Roland J. White and Victor J. Martin, 12 pages, illustrations. No. 581, A Study of Autogiro Rotor-Blade Oscillations in the Plane of the Rotor Disk, by John B. Wheatley, 14 pages, illustrations. 2 pamphlets, 20 × 26 cms. Washington, Committee, 1936.

CURRENT TOPICS.

Absorption and Extraction. The Division of Industrial and Engineering Chemistry of the American Chemical Society, will hold its Third December Chemical Engineering Symposium on Absorption and Extraction at Columbia University on Monday and Tuesday, December 28th and 29th. The program is well advanced and definite promises of papers have been received, being equally divided between the two related topics. As has been the practice in previous symposia, the contributors are from both industrial and educational organizations and institutions. Reports are expected on research, conducted at the Universiy of Birmingham, England, Drexel Institute, University of Illinois, Massachusetts Institute of Technology, Pennsylvania State College, Princeton University and the University of Virginia. There will also be a number of papers contributed by members of the chemical engineering staffs of leading oil companies and equipment manufacturers.

R.

The Velocity of Radio Waves.—R. C. COLWELL. (*The Electric Journal*, Vol. 33, No. 10.) The use of 60 cycle alternating current power lines for synchronizing radio transmitting and receiving equipment at two distant stations is making possible the measurement of the velocity of propagation of radio waves. The base station (Experimental W8XAW) is located at West Virginia University in Morgantown. A second semi-portable station, originally 50 miles away in Elkins, is now being operated about 12 miles away in Fairmont. The velocity of propagation is being determined by measuring the time required for a very short radio frequency pulse to travel from the base station to the field station and back again. This method of velocity measurement is an adaptation of the method of Breit and Tuve for determining the height of the ionosphere. It differs in that a second station a known distance from the base station takes the place of an ionized layer as the means of reflecting the waves back to the base station. At the present time the experimental data are far from complete, but preliminary tests indicate that the ground wave is propagated with about two-thirds the velocity of light. The accuracy of the measurements is better than that ordinarily obtained in the determination of ionospheric height.

R. H. O.